

### **Liquid-crystalline medium**

The present invention relates to a liquid-crystalline medium, to the use thereof for electro-optical purposes, and to displays containing this medium.

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Liquid-crystals are used principally as dielectrics in display devices, since the optical properties of such substances can be modified by an applied voltage. Electro-optical devices based on liquid crystals are extremely well known to the person skilled in the art and can be based on various effects.

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Examples of such devices are cells having dynamic scattering, DAP (deformation of aligned phases) cells, guest/host cells, TN cells having a twisted nematic structure, STN (supertwisted nematic) cells, SBE (super-birefringence effect) cells and OMI (optical mode interference) cells. The commonest display devices are based on the Schadt-Helfrich effect and

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have a twisted nematic structure.

The liquid-crystal materials must have good chemical and thermal stability and good stability to electric fields and electromagnetic radiation. Furthermore, the liquid-crystal materials should have low viscosity and produce short addressing times, low threshold voltages and high contrast in the

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cells.

They should furthermore have a suitable mesophase, for example a nematic or cholesteric mesophase for the above-mentioned cells, at the usual operating temperatures, i.e. in the broadest possible range above and below room temperature. Since liquid crystals are generally used as mixtures of a plurality of components, it is important that the components are readily miscible with one another. Further properties, such as the electrical conductivity, the dielectric anisotropy and the optical anisotropy, have to satisfy various requirements depending on the cell type and area of application. For example, materials for cells having a twisted nematic structure should have positive dielectric anisotropy and low electrical conductivity.

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For example, for matrix liquid-crystal displays with integrated non-linear elements for switching individual pixels (MLC displays), media having large positive dielectric anisotropy, broad nematic phases, relatively low birefringence, very high specific resistance, good UV and temperature stability and lower vapour pressure are desired.

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Matrix liquid-crystal displays of this type are known. Non-linear elements which can be used for individual switching of the individual pixels are, for example, active elements (i.e. transistors). The term "active matrix" is then used, where a distinction can be made between two types:

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1. MOS (metal oxide semiconductor) or other diodes on a silicon wafer as substrate.
2. Thin-film transistors (TFTs) on a glass plate as substrate.

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The use of single-crystal silicon as substrate material restricts the display size, since even modular assembly of various part-displays results in problems at the joins.

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In the case of the more promising type 2, which is preferred, the electro-optical effect used is usually the TN effect. A distinction is made between two technologies: TFTs comprising compound semiconductors, such as, for example, CdSe, or TFTs based on polycrystalline or amorphous silicon. Intensive work is being carried out world-wide on the latter technology.

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The TFT matrix is applied to the inside of one glass plate of the display, while the other glass plate carries the transparent counterelectrode on its inside. Compared with the size of the pixel electrode, the TFT is very small and has virtually no adverse effect on the image. This technology can also be extended to fully colour-capable displays, in which a mosaic of red, green and blue filters is arranged in such a way that a filter element is opposite each switchable pixel.

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The TFT displays usually operate as TN cells with crossed polarisers in transmission and are illuminated from the back.

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The term MLC displays here covers any matrix display with integrated non-linear elements, i.e., besides the active matrix, also displays with passive elements, such as varistors or diodes (MIM = metal-insulator-metal).

5 MLC displays of this type are particularly suitable for TV applications (for example pocket TVs) or for high-information displays for computer applications (laptops) and in automobile or aircraft construction. Besides problems regarding the angle dependence of the contrast and the response times, difficulties also arise in MLC displays due to insufficiently high  
10 specific resistance of the liquid-crystal mixtures [TOGASHI, S., SEKOGUCHI, K., TANABE, H., YAMAMOTO, E., SORIMACHI, K., TAJIMA, E., WATANABE, H., SHIMIZU, H., Proc. Eurodisplay 84, Sept. 1984: A 210-288 Matrix LCD Controlled by Double Stage Diode Rings, p. 141 ff, Paris; STROMER, M., Proc. Eurodisplay 84, Sept. 1984: Design  
15 of Thin Film Transistors for Matrix Addressing of Television Liquid Crystal Displays, p. 145 ff, Paris]. With decreasing resistance, the contrast of an MLC display deteriorates, and the problem of after-image elimination may occur. Since the specific resistance of the liquid-crystal mixture generally drops over the life of an MLC display owing to interaction with the interior  
20 surfaces of the display, a high (initial) resistance is very important in order to obtain acceptable service lives. In particular in the case of low-volt mixtures, it was hitherto impossible to achieve very high specific resistance values. It is furthermore important that the specific resistance exhibits the smallest possible increase with increasing temperature and after heating  
25 and/or UV exposure. The low-temperature properties of the mixtures from the prior art are also particularly disadvantageous. It is demanded that no crystallisation and/or smectic phases occur, even at low temperatures, and the temperature dependence of the viscosity is as low as possible. The MLC displays from the prior art thus do not meet today's requirements.

30 There thus continues to be a great demand for MLC displays having very high specific resistance at the same time as a large working-temperature range, short response times even at low temperatures and low threshold voltage which do not have these disadvantages, or only do so to a reduced  
35 extent.

In addition to liquid-crystal displays which use back-lighting, i.e. are operated transmissively and if desired transflectively, reflective liquid-crystal displays are also particularly interesting. These reflective liquid-crystal displays use the ambient light for information display. They thus consume significantly less energy than back-lit liquid-crystal displays having a corresponding size and resolution. Since the TN effect is characterised by very good contrast, reflective displays of this type can even be read well in bright ambient conditions. This is already known of simple reflective TN displays, as used, for example, in watches and pocket calculators. However, the principle can also be applied to high-quality, higher-resolution active matrix-addressed displays, such as, for example, TFT displays. Here, as already in the transmissive TFT-TN displays which are generally conventional, the use of liquid crystals of low birefringence ( $\Delta n$ ) is necessary in order to achieve low optical retardation ( $d \cdot \Delta n$ ). This low optical retardation results in usually acceptable low viewing-angle dependence of the contrast (cf. DE 30 22 818). In reflective displays, the use of liquid crystals of low birefringence is even more important than in transmissive displays since the effective layer thickness through which the light passes is approximately twice as large in reflective displays as in transmissive displays having the same layer thickness.

In TN (Schadt-Helfrich) cells, media are desired which facilitate the following advantages in the cells:

- extended nematic phase range (in particular down to low temperatures)
- stable on storage, even at low temperatures
- the ability to switch at extremely low temperatures (outdoor use, automobile, avionics)
- increased resistance to UV radiation (longer service life)
- low optical birefringence ( $\Delta n$ ) for reflective displays.

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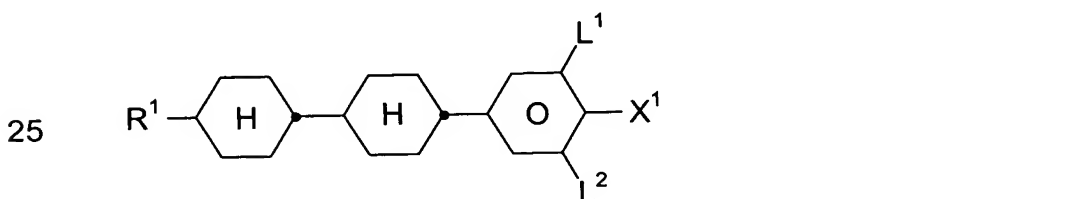
The media available from the prior art do not allow these advantages to be achieved while simultaneously retaining the other parameters.

In the case of supertwisted (STN) cells, media are desired which enable greater multiplexability and/or lower threshold voltages and/or broader nematic phase ranges (in particular at low temperatures). To this end, a further widening of the available parameter latitude (clearing point, smectic-nematic transition or melting point, viscosity, dielectric parameters, elastic parameters) is urgently desired.

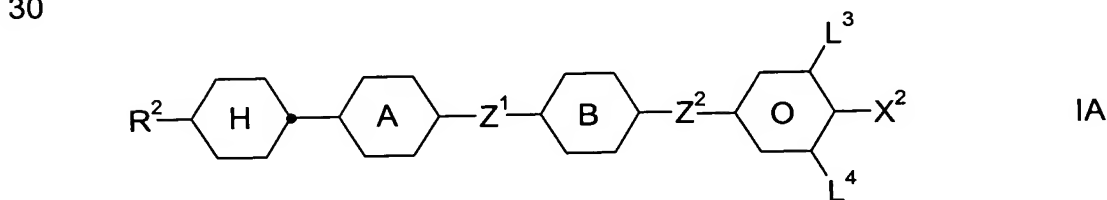
The invention has the object of providing media, in particular for MLC, TN or STN displays of this type, which do not have the above-mentioned disadvantages or only do so to a reduced extent, and preferably simultaneously have very low threshold voltages and at the same time high values for the voltage holding ratio (VHR).

It has now been found that this object can be achieved if media according to the invention are used in displays.

The invention thus relates to a liquid-crystalline medium based on a mixture of polar compounds of positive dielectric anisotropy, characterised in that it comprises one or more compounds of the formula I




and one or more compounds of the formula IA



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in which the individual radicals have the following meanings:


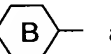
5  $R^1$  and  $R^2$  are each, independently of one another, H, a halogenated or unsubstituted alkyl radical having from 1 to 15 carbon atoms, where one or more  $CH_2$  groups in these radicals may also be replaced, in each case independently of one another, by  $-C\equiv C-$ ,  $-CH=CH-$ ,  $-O-$ , ,  $-CO-O-$  or  $-O-CO-$  in such a way that O atoms are not linked directly to one another,

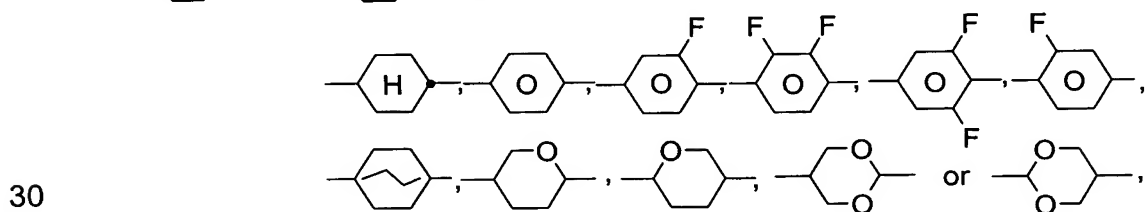
10  $X^1$  is  $CN$ ,  $SF_5$ ,  $SCN$ ,  $NCS$ ,  $OCN$ , a halogenated alkyl radical, a halogenated alkenyl radical, a halogenated alkoxy radical or a halogenated alkenyloxy radical, each having up to 6 carbon atoms,

15  $X^2$  is in each case, independently of one another,  $F$ ,  $Cl$ ,  $CN$ ,  $SF_5$ ,  $SCN$ ,  $NCS$ ,  $OCN$ , a halogenated alkyl radical, a halogenated alkenyl radical, a halogenated alkoxy radical or a halogenated alkenyloxy radical, each having up to 6 carbon atoms,

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$Z^1$  and  $Z^2$  are each, independently of one another,  $-CF_2O-$ ,  $-OCF_2-$  or a single bond, where  $Z^1 \neq Z^2$ ,

25  and  are each, independently of one another,



$L^{1-4}$  are each, independently of one another, H or F.

35 The compounds of the formulae I and IA have a broad range of applications. Depending on the choice of substituents, these compounds can

serve as base materials of which liquid-crystalline media are predominantly composed; however, it is also possible to add compounds of the formulae I and IA to liquid-crystalline base materials from other classes of compound in order, for example, to modify the dielectric and/or optical anisotropy of a dielectric of this type and/or in order to optimise its threshold voltage and/or its viscosity. The mixing concept according to the invention results in mixtures which are distinguished over the prior art through their very good reliability and  $V_{th}/\gamma_1$  ratio, in particular in 2.5 V and 3.3 V mixtures.

In the pure state, the compounds of the formulae I and IA are colourless and form liquid-crystalline mesophases in a temperature range which is favourably located for electro-optical use. They are stable chemically, thermally and to light.

If  $R^1$  and/or  $R^2$  are an alkyl radical and/or an alkoxy radical, this may be straight-chain or branched. It is preferably straight-chain, has 2, 3, 4, 5, 6 or 7 carbon atoms and accordingly is preferably methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, ethoxy, propoxy, butoxy, pentoxy, hexyloxy or heptyloxy, furthermore octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, methoxy, octyloxy, nonyloxy, decyloxy, undecyloxy, dodecyloxy, tridecyloxy or tetradecyloxy.

Oxaalkyl is preferably straight-chain 2-oxapropyl (= methoxymethyl), 2-(= ethoxymethyl) or 3-oxabutyl (= 2-methoxyethyl), 2-, 3- or 4-oxapentyl, 2-, 3-, 4- or 5-oxahexyl, 2-, 3-, 4-, 5- or 6-oxaheptyl, 2-, 3-, 4-, 5-, 6- or 7-oxaoctyl, 2-, 3-, 4-, 5-, 6-, 7- or 8-oxanonyl, or 2-, 3-, 4-, 5-, 6-, 7-, 8- or 9-oxadecyl.

If  $R^1$  and/or  $R^2$  are an alkyl radical in which one  $CH_2$  group has been replaced by  $-CH=CH-$ , this may be straight-chain or branched. It is preferably straight-chain and has 2 to 10 carbon atoms. Accordingly, it is in particular vinyl, prop-1- or prop-2-enyl, but-1-, -2- or -3-enyl, pent-1-, -2-, -3- or -4-enyl, hex-1-, -2-, -3-, -4- or -5-enyl, hept-1-, -2-, -3-, -4-, -5- or -6-enyl, oct-1-, -2-, -3-, -4-, -5-, -6- or -7-enyl, non-1-, -2-, -3-, -4-, -5-, -6-, -7- or -8-enyl, or dec-1-, -2-, -3-, -4-, -5-, -6-, -7-, -8- or -9-enyl.

If  $R^1$  and/or  $R^2$  are an alkyl radical in which one  $CH_2$  group has been replaced by -O- and one has been replaced by -CO-, these are preferably adjacent. These thus contain an acyloxy group -CO-O- or an oxycarbonyl group -O-CO-. These are preferably straight-chain and have 2 to 6 carbon atoms. Accordingly, they are in particular acetoxymethyl, propionyloxymethyl, butyryloxymethyl, pentanoyloxymethyl, 2-acetoxyethyl, 2-propionyloxyethyl, 2-butyryloxyethyl, 3-acetoxypentyl, 3-propionyloxypropyl, 4-acetoxybutyl, methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, butoxycarbonyl, pentoxycarbonyl, methoxycarbonylmethyl, ethoxycarbonylmethyl, propoxycarbonylmethyl, butoxycarbonylmethyl, 2-(methoxycarbonyl)ethyl, 2-(ethoxycarbonyl)ethyl, 2-(propoxycarbonyl)ethyl, 3-(methoxycarbonyl)propyl, 3-(ethoxycarbonyl)propyl or 4-(methoxycarbonyl)butyl.

If  $R^1$  and/or  $R^2$  are an alkyl radical in which one  $CH_2$  group has been replaced by unsubstituted or substituted -CH=CH- and an adjacent  $CH_2$  group has been replaced by CO or CO-O or O-CO, this may be straight-chain or branched. It is preferably straight-chain and has 4 to 12 carbon atoms. Accordingly, it is in particular acryloyloxymethyl, 2-acryloyloxyethyl, 3-acryloyloxypropyl, 4-acryloyloxybutyl, 5-acryloyloxypropyl, 6-acryloyloxyhexyl, 7-acryloyloxyheptyl, 8-acryloyloxyoctyl, 9-acryloyloxynonyl, 10-acryloyloxydecyl, methacryloyloxymethyl, 2-methacryloyloxyethyl, 3-methacryloyloxypropyl, 4-methacryloyloxybutyl, 5-methacryloyloxypropyl, 6-methacryloyloxyhexyl, 7-methacryloyloxyheptyl, 8-methacryloyloxyoctyl or 9-methacryloyloxynonyl.

If  $R^1$  and/or  $R^2$  are an alkyl or alkenyl radical which is monosubstituted by CN or  $CF_3$ , this radical is preferably straight-chain. The substitution by CN or  $CF_3$  is in any desired position.

If  $R^1$  and/or  $R^2$  are an alkyl or alkenyl radical which is at least monosubstituted by halogen, this radical is preferably straight-chain, and halogen is preferably F or Cl. In the case of polysubstitution, halogen is preferably F. The resultant radicals also include perfluorinated radicals. In the case of monosubstitution, the fluorine or chlorine substituent may be in any desired position, but is preferably in the  $\omega$ -position.



Compounds containing branched wing groups  $R^1$  and/or  $R^2$  may occasionally be of importance owing to better solubility in the conventional liquid-crystalline base materials, but in particular as chiral dopants if they are optically active. Smectic compounds of this type are suitable as components of ferroelectric materials.

Branched groups of this type generally contain not more than one chain branch. Preferred branched radicals R are isopropyl, 2-butyl (= 1-methylpropyl), isobutyl (= 2-methylpropyl), 2-methylbutyl, isopentyl (= 3-methylbutyl), 2-methylpentyl, 3-methylpentyl, 2-ethylhexyl, 2-propylpentyl, isopropoxy, 2-methylpropoxy, 2-methylbutoxy, 3-methylbutoxy, 2-methylpentoxy, 3-methylpentoxy, 2-ethylhexyloxy, 1-methylhexyloxy and 1-methylheptyloxy.

If  $R^1$  and/or  $R^2$  are an alkyl radical in which two or more  $CH_2$  groups have been replaced by -O- and/or -CO-O-, this may be straight-chain or branched. It is preferably branched and has from 3 to 12 carbon atoms. Accordingly, it is in particular biscalboxymethyl, 2,2-biscalboxyethyl, 3,3-biscalboxypropyl, 4,4-biscalboxybutyl, 5,5-biscalboxypentyl, 6,6-biscalboxyhexyl, 7,7-biscalboxyheptyl, 8,8-biscalboxyoctyl, 9,9-biscalboxynonyl, 10,10-biscalboxydecyl, bis(methoxycarbonyl)methyl, 2,2-bis(methoxycarbonyl)ethyl, 3,3-bis(methoxycarbonyl)propyl, 4,4-bis(methoxycarbonyl)butyl, 5,5-bis(methoxycarbonyl)pentyl, 6,6-bis(methoxycarbonyl)hexyl, 7,7-bis(methoxycarbonyl)heptyl, 8,8-bis(methoxycarbonyl)octyl, bis(ethoxycarbonyl)methyl, 2,2-bis(ethoxycarbonyl)ethyl, 3,3-bis(ethoxycarbonyl)propyl, 4,4-bis(ethoxycarbonyl)butyl or 5,5-bis(ethoxycarbonyl)pentyl.

The compounds of the formulae I and IA are prepared by methods known per se, as described in the literature (for example in the standard works, such as Houben-Weyl, Methoden der organischen Chemie [Methods of Organic Chemistry], Georg-Thieme-Verlag, Stuttgart), to be precise under reaction conditions which are known and suitable for the said reactions. Use can also be made here of variants which are known per se, but are not mentioned here in greater detail. The compounds of the formula IA are

known, for example, from EP 1 046 693 A1 and EP 1 046 694 A1. The compounds of the formula I are described, for example, in EP 0 334 911 B1.

5 The invention also relates to electro-optical displays (in particular STN or MLC displays having two plane-parallel outer plates, which, together with a frame, form a cell, integrated non-linear elements for switching individual pixels on the outer plates, and a nematic liquid-crystal mixture of positive dielectric anisotropy and high specific resistance which is located in the cell) which contain media of this type, and to the use of these media for  
10 electro-optical purposes.

The liquid-crystal mixtures according to the invention enable a significant widening of the available parameter latitude.

15 The achievable combinations of clearing point, viscosity at low temperature, thermal and UV stability and dielectric anisotropy are far superior to previous materials from the prior art.

20 Compared with the mixtures disclosed in EP 1 046 693 A1, the mixtures according to the invention have a higher clearing point, low  $\gamma_1$  values and very high values for the VHR at 100°C. The mixtures according to the invention are preferably suitable as TN-TFT mixtures for notebook PC applications with 3.3 and 2.5 V drivers.

25 The liquid-crystal mixtures according to the invention, while retaining the nematic phase down to -30°C, particularly preferably down to -40°C, enable clearing points above 70°C, preferably above 75°C, particularly preferably above 80°C, simultaneously dielectric anisotropy values  $\Delta\epsilon$  of  $\geq 6$ , preferably  $\geq 8$ , and a high value for the specific resistance to be  
30 achieved, enabling excellent STN and MLC displays to be obtained. In particular, the mixtures are characterised by low operating voltages. The TN thresholds are below 1.8 V, preferably below 1.5 V, particularly preferably  $< 1.3$  V.

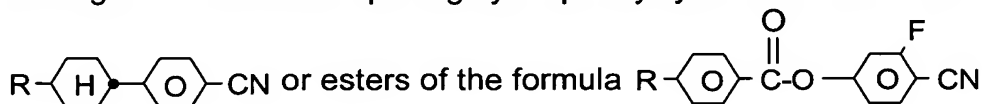
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It goes without saying that, through a suitable choice of the components of the mixtures according to the invention, it is also possible for higher clearing points (for example above 110°C) to be achieved at a higher threshold voltage or lower clearing points to be achieved at lower threshold voltages with retention of the other advantageous properties. At viscosities correspondingly increased only slightly, it is likewise possible to obtain mixtures having greater  $\Delta\epsilon$  and thus lower thresholds. The MLC displays according to the invention preferably operate at the first Gooch and Tarry transmission minimum [C.H. Gooch and H.A. Tarry, Electron. Lett. 10, 2-4, 1974; C.H. Gooch and H.A. Tarry, Appl. Phys., Vol. 8, 1575-1584, 1975] are used, where, besides particularly favourable electro-optical properties, such as, for example, high steepness of the characteristic line and low angle dependence of the contrast (German Patent 30 22 818), a lower dielectric anisotropy is sufficient at the same threshold voltage as in an analogous display at the second minimum. This enables significantly higher specific resistances to be achieved using the mixtures according to the invention at the first minimum than in the case of mixtures comprising cyano compounds. Through a suitable choice of the individual components and their proportions by weight, the person skilled in the art is able to set the birefringence necessary for a pre-specified layer thickness of the MLC display using simple routine methods.

The flow viscosity  $\nu_{20}$  at 20°C is preferably  $< 60 \text{ mm}^2 \cdot \text{s}^{-1}$ , particularly preferably  $< 50 \text{ mm}^2 \cdot \text{s}^{-1}$ . The rotational viscosity  $\gamma_1$  at 20°C of the mixtures according to the invention is preferably  $< 140 \text{ mPa} \cdot \text{s}$ , particularly preferably  $< 120 \text{ mPa} \cdot \text{s}$ . The nematic phase range is preferably at least 100°, in particular at least 110°. This range preferably extends at least from -40° to +80°C.

A short response time is desired in liquid-crystal displays. This applies in particular to displays which are capable of video reproduction. For displays of this type, response times (sum:  $t_{\text{on}} + t_{\text{off}}$ ) of at most 16 ms are required. The upper limit of the response time is determined by the image refresh frequency.

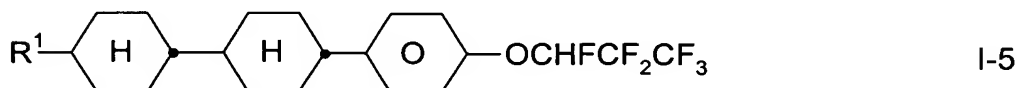
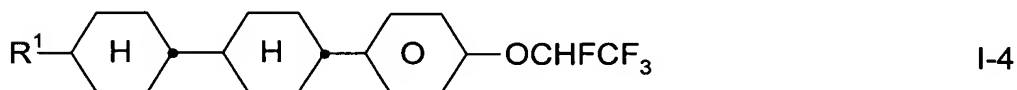
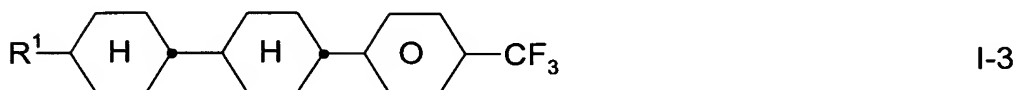
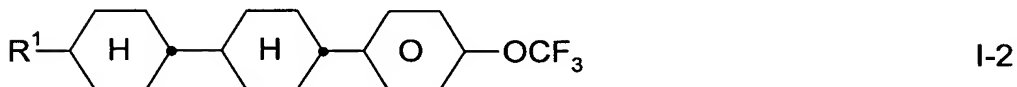
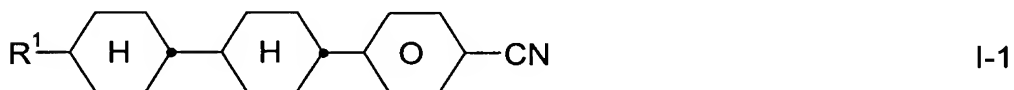
Measurements of the voltage holding ratio (HR) [S. Matsumoto et al., Liquid Crystals 5, 1320 (1989); K. Niwa et al., Proc. SID Conference, San Francisco, June 1984, p. 304 (1984); G. Weber et al., Liquid Crystals 5, 1381 (1989)] have shown that mixtures according to the invention comprising compounds of the formulae I and IA exhibit a significantly smaller decrease in the HR with increasing temperature than, for example, analogous mixtures comprising cyanophenylcyclohexanes of the formula



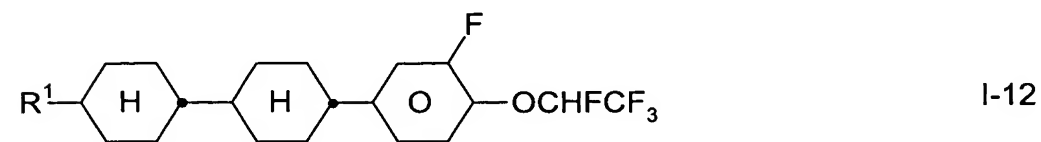
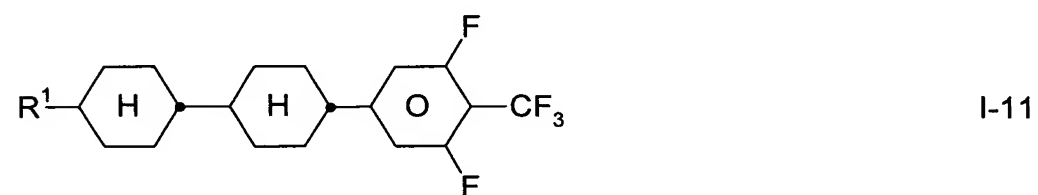
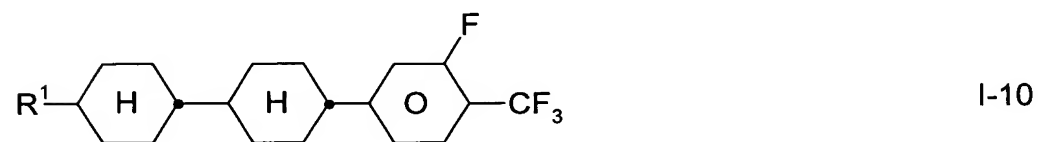
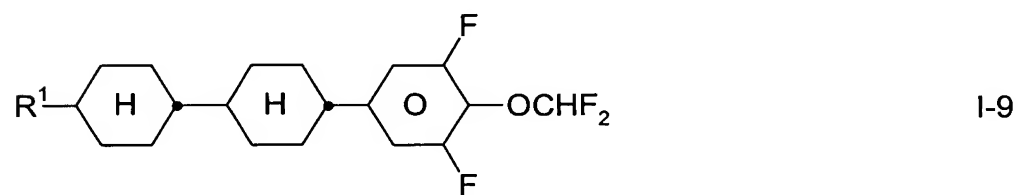
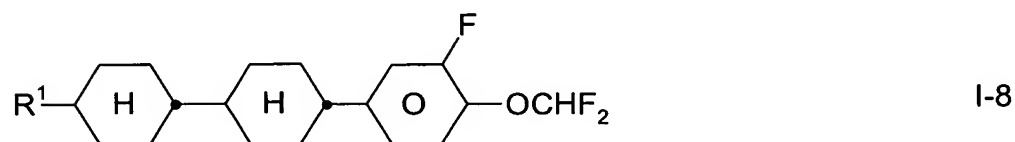
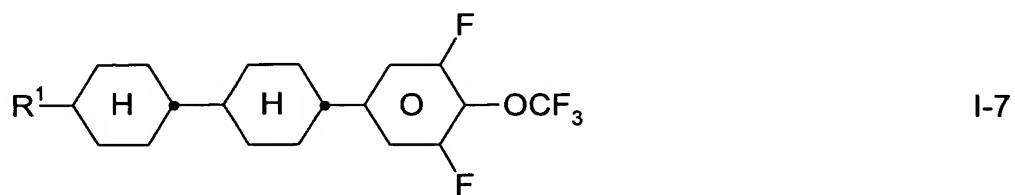
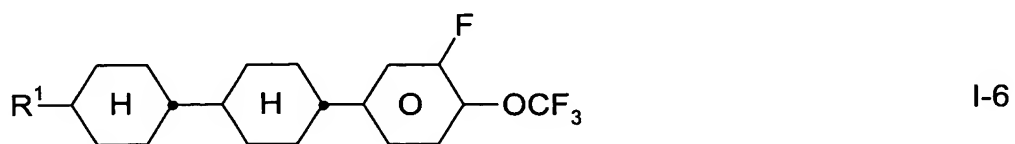
instead of the compounds of the formula IA.

The UV stability of the mixtures according to the invention is also considerably better, i.e. they exhibit a significantly smaller decrease in the HR on exposure to UV.

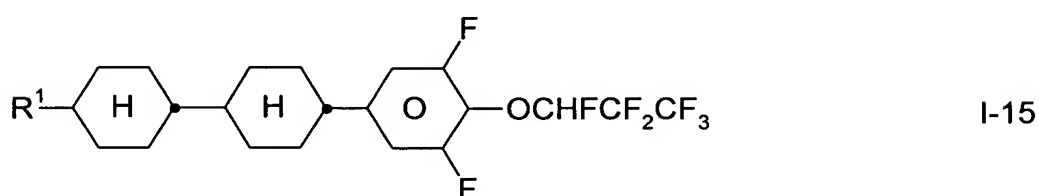
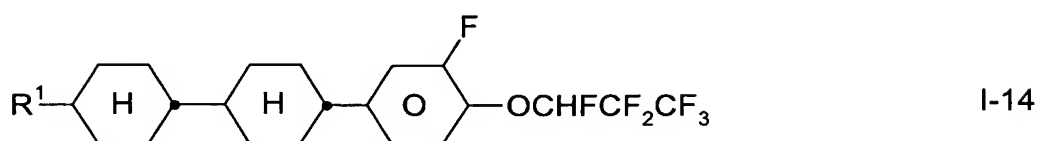
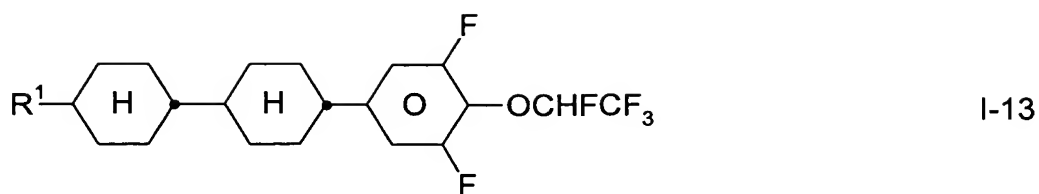
Formula I preferably covers compounds of the formulae I-1 to I-15:



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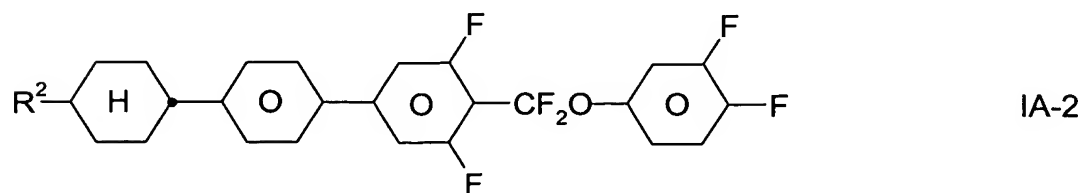
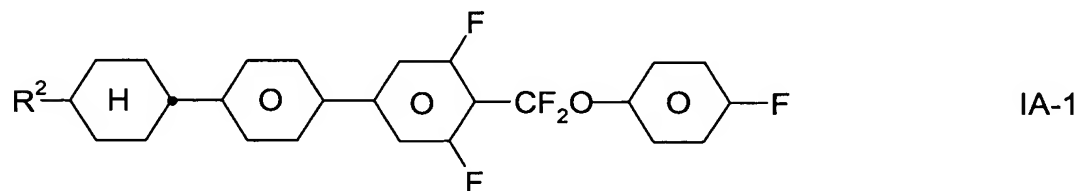
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in which R<sup>1</sup> is as defined in Claim 1. R<sup>1</sup> is preferably H, CH<sub>3</sub>, C<sub>2</sub>H<sub>5</sub>, n-C<sub>3</sub>H<sub>7</sub>, n-C<sub>4</sub>H<sub>9</sub>, n-C<sub>5</sub>H<sub>11</sub>, n-C<sub>6</sub>H<sub>13</sub>, CH<sub>2</sub>=CH, CH<sub>3</sub>CH=CH, CH<sub>3</sub>CH=CHCH<sub>2</sub>CH<sub>2</sub> or CH<sub>2</sub>=CHCH<sub>2</sub>CH<sub>2</sub>.

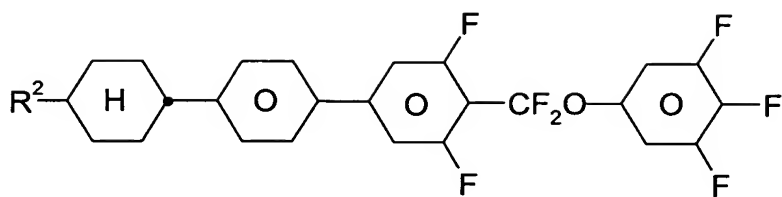
Preference is given to media according to the invention which comprise at least one compound of the formulae I-2, I-6, I-7 and/or I-9, particularly preferably in each case at least one compound of the formula I-2.

Particularly preferred compounds of the formula IA are compounds of the formulae IA-1 to IA-24:



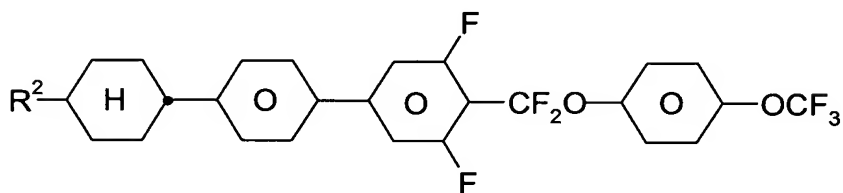
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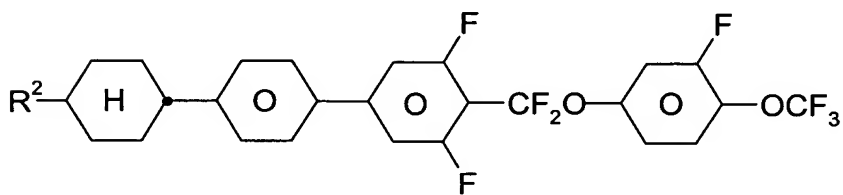
IA-3

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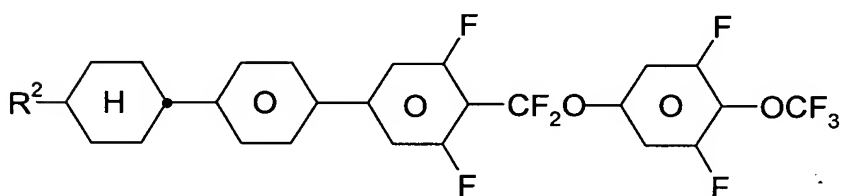
IA-4

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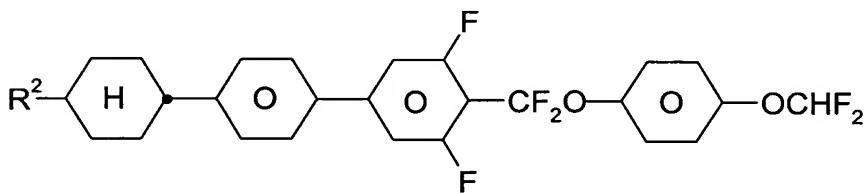
IA-5

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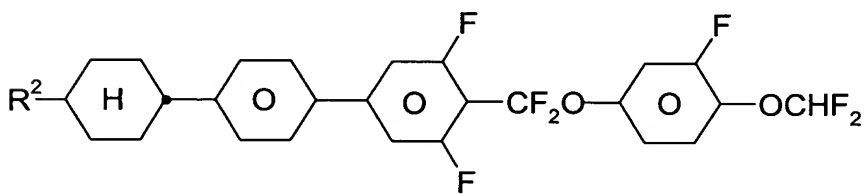
IA-6

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IA-7

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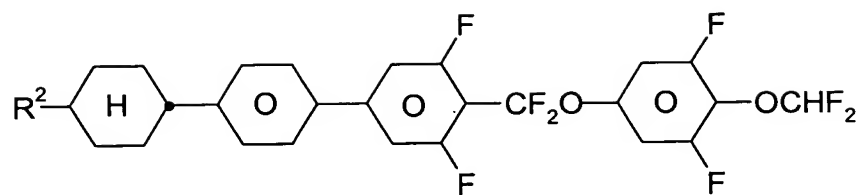


IA-8

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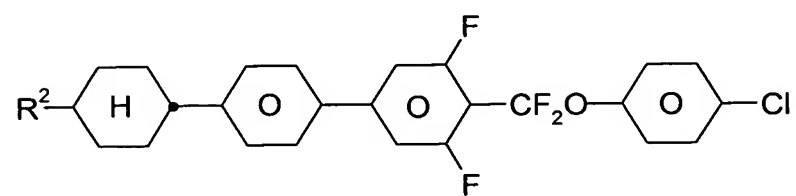
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- 16 -



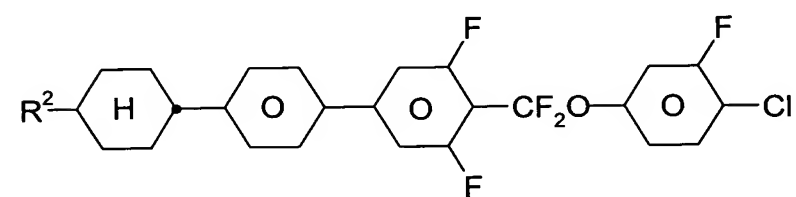
1A-9

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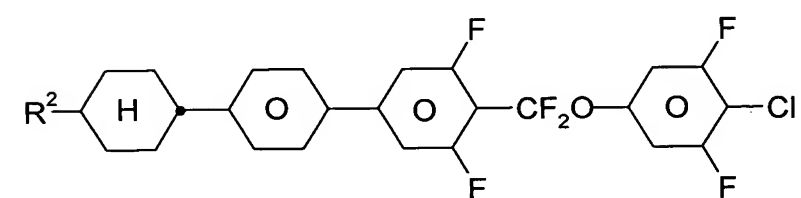
IA-10

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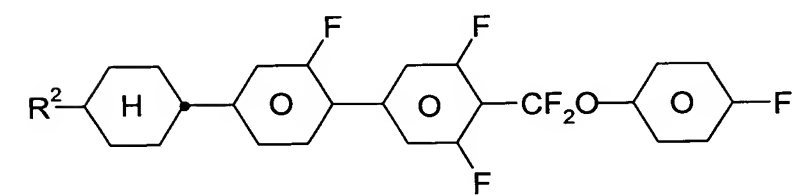
IA-11

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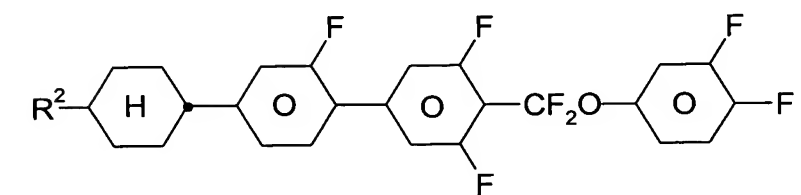
IA-12

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IA-13

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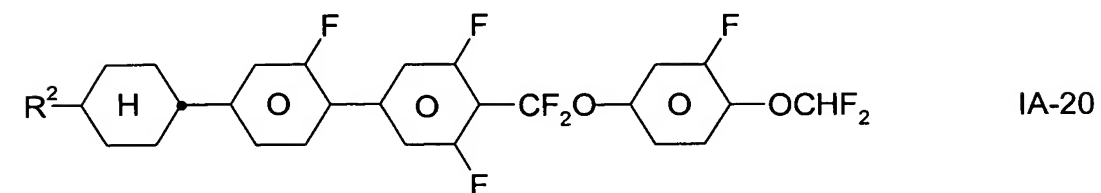
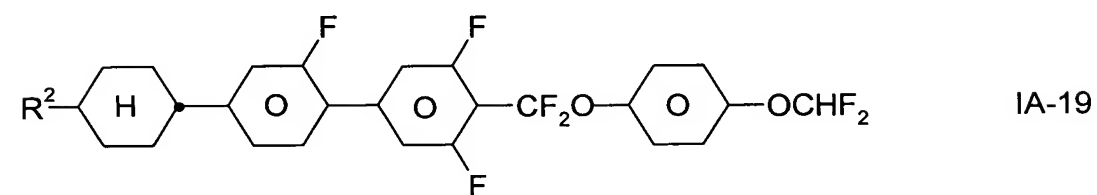
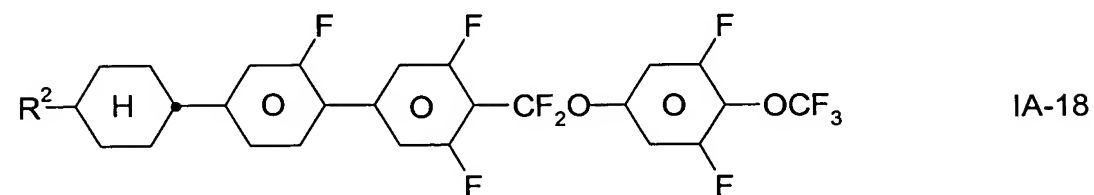
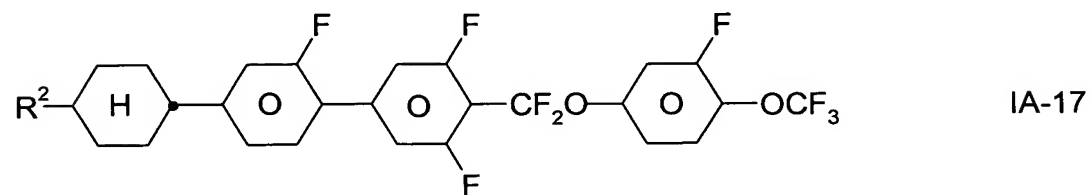
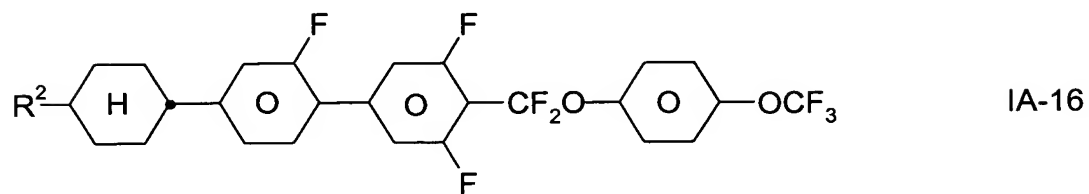
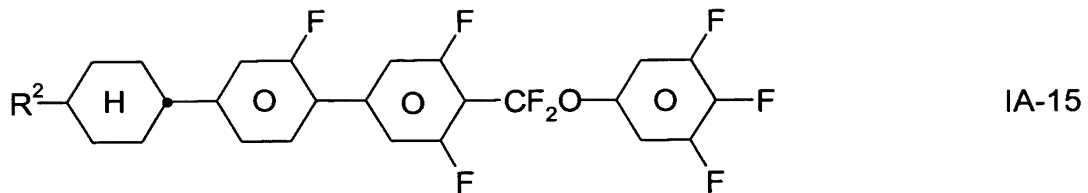
1A-14

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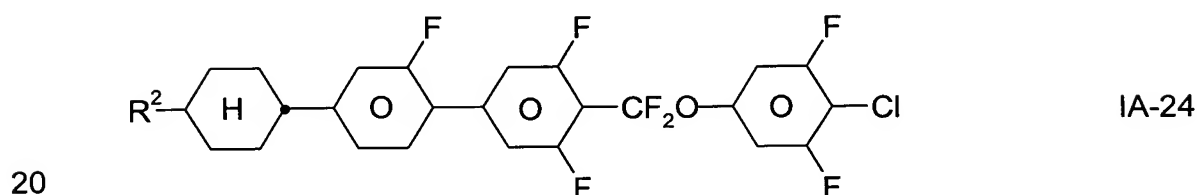
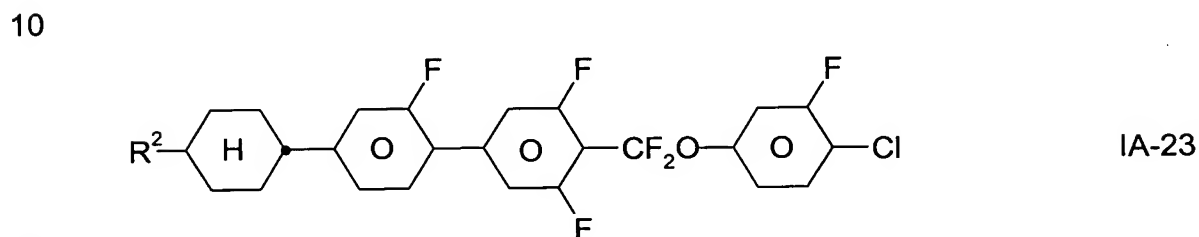
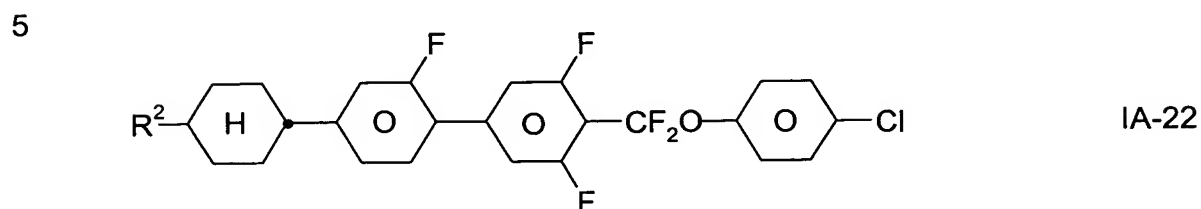
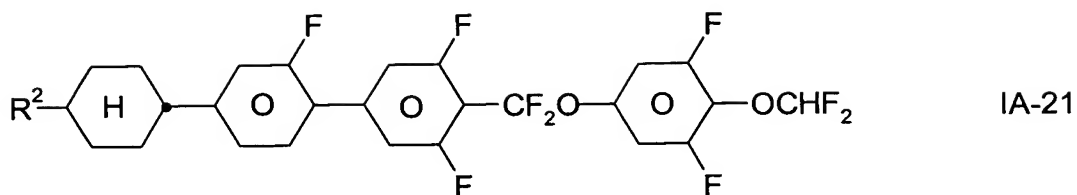
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- 17 -



- 18 -



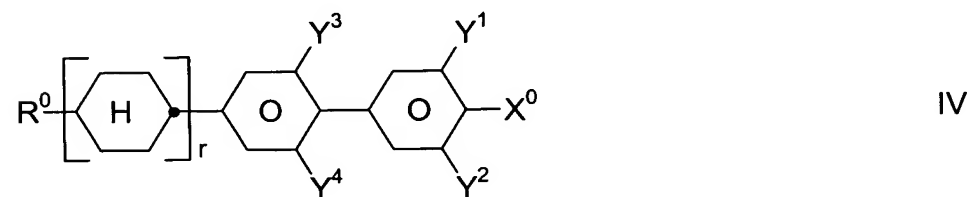
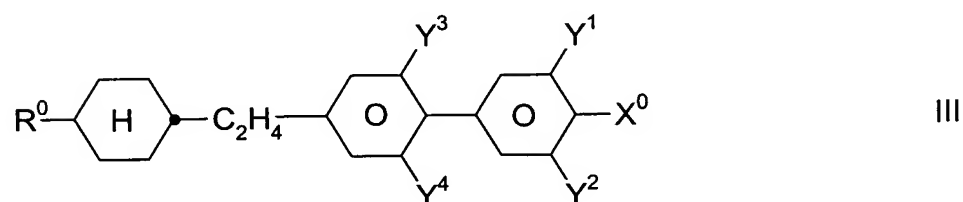
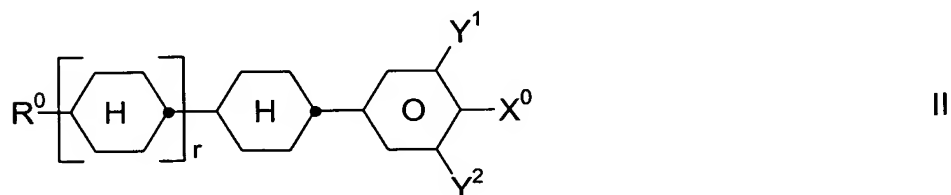
in which R<sup>2</sup> is as defined above.

Of these preferred compounds, particular preference is given to those of the formulae IA-2, IA-3, IA-5, IA-6 and IA-14, IA-15 and IA-18, in particular those of the formulae IA-3 and IA-15.

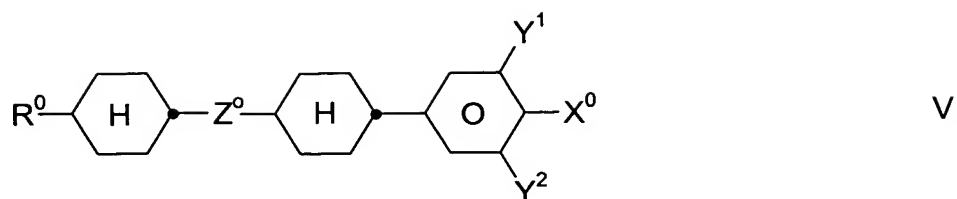
R<sup>2</sup> in the compounds of the formulae IA and IA1 to IA-24 is preferably H, straight-chain alkyl having from 1 to 7 carbon atoms, in particular CH<sub>3</sub>, C<sub>2</sub>H<sub>5</sub>, n-C<sub>3</sub>H<sub>7</sub>, n-C<sub>4</sub>H<sub>9</sub>, n-C<sub>5</sub>H<sub>11</sub>, n-C<sub>6</sub>H<sub>13</sub>, n-C<sub>7</sub>H<sub>15</sub>, furthermore 1E- or 3-alkenyl, in particular CH<sub>2</sub>=CH, CH<sub>3</sub>CH=CH, CH<sub>2</sub>=CHCH<sub>2</sub>CH<sub>2</sub> or CH<sub>3</sub>CH=CH-CH<sub>2</sub>CH<sub>2</sub>.

Preferred embodiments are indicated below:

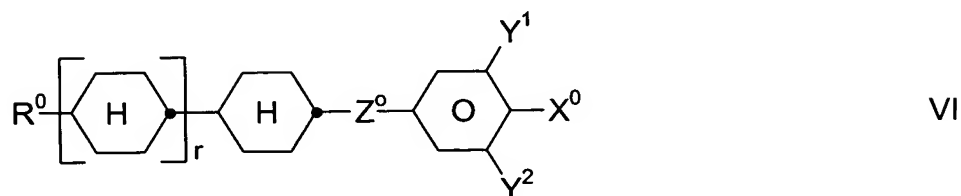
- The medium comprises one, two or more compounds selected from the group consisting of the formulae IA-1 to IA-24;
- The medium preferably comprises in each case one or more, preferably two or three, compounds (homologues) of the formulae I-1 and IA-15;
- The medium preferably comprises in each case one or more, preferably two or three, compounds (homologues) of the formulae I-1 and IA-3;
- The medium additionally comprises one or more compounds selected from the group consisting of the general formulae II to VI:



- 20 -



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in which the individual radicals are as defined below:

15  $\text{R}^0$  is n-alkyl, alkoxy, oxaalkyl, fluoroalkyl or alkenyl, each having up to 9 carbon atoms,

$\text{X}^0$  is F, Cl, halogenated alkyl, alkenyl, alkenyloxy or alkoxy having up to 6 carbon atoms,

20  $\text{Z}^0$  is  $-\text{C}_2\text{F}_4-$ ,  $-\text{CF}=\text{CF}-$ ,  $-\text{CH}=\text{CF}-$ ,  $-\text{CF}=\text{CH}-$ ,  $-\text{C}_2\text{H}_4-$ ,  $-(\text{CH}_2)_4-$ ,  $-\text{CF}_2\text{O}-$ ,  $-\text{OCF}_2-$ ,  $-\text{OCH}_2-$  or  $-\text{CH}_2\text{O}-$ ,

$\text{Y}^1$  and  $\text{Y}^2$  are each, independently of one another, H or F,

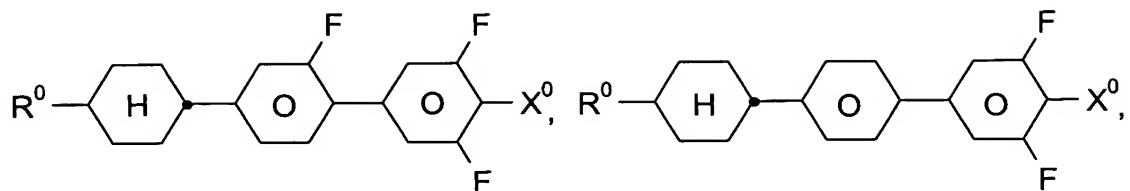
25  $r$  is 0 or 1,

where the compound of the formula II is not identical with the formula I.

30 The compound of the formula IV is preferably

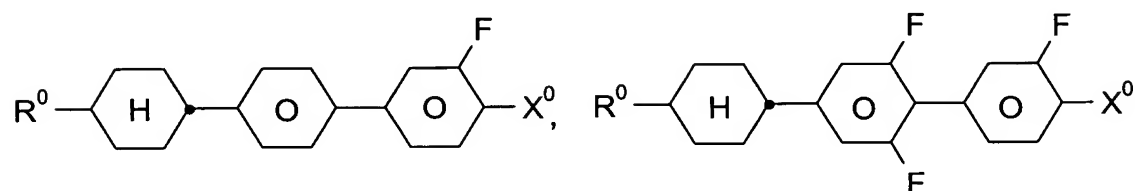
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- 21 -



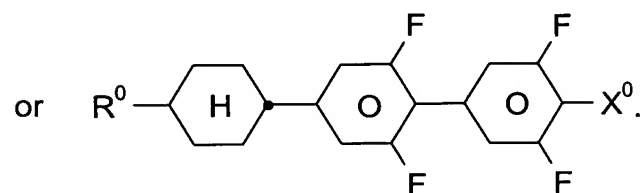
IVa

IVb



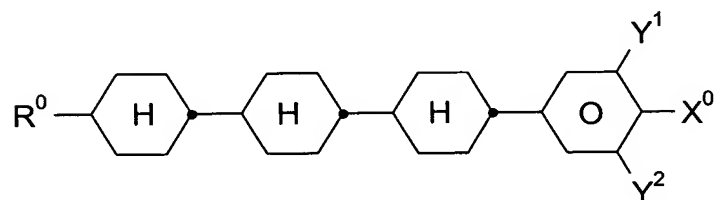
IVc

IVd

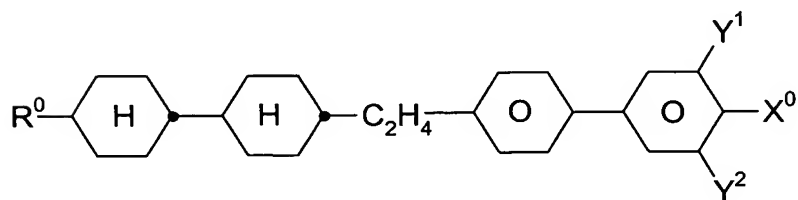


IVe

- The medium additionally comprises one or more compounds selected from the group consisting of the general formulae VII to XIII:

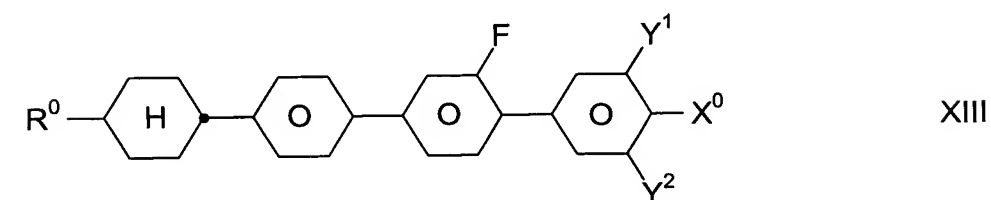
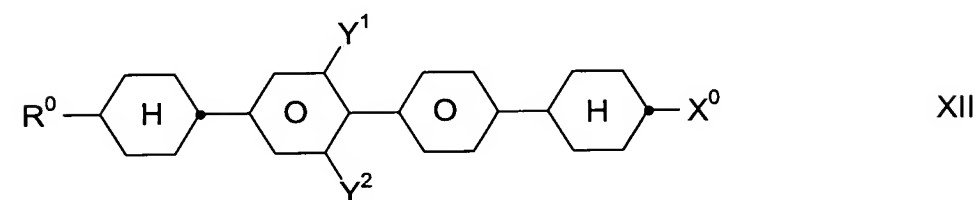
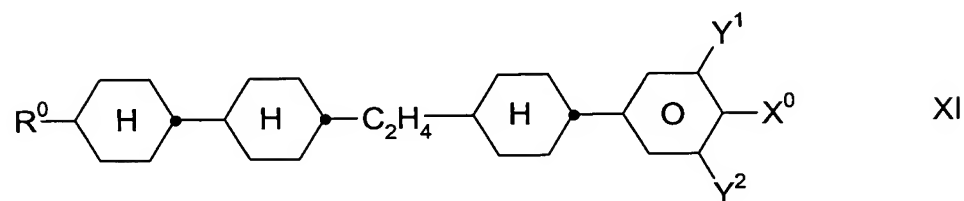
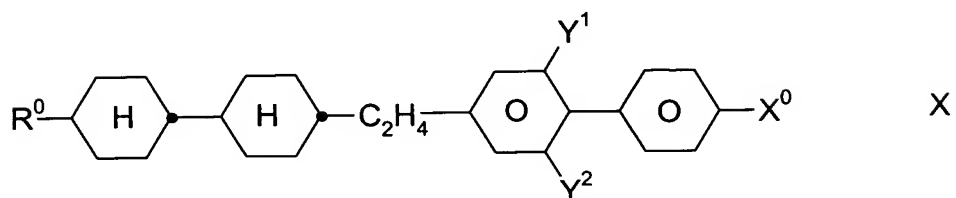
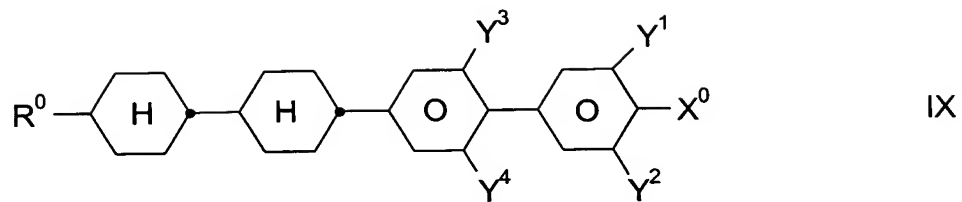


VII



VIII

- 22 -

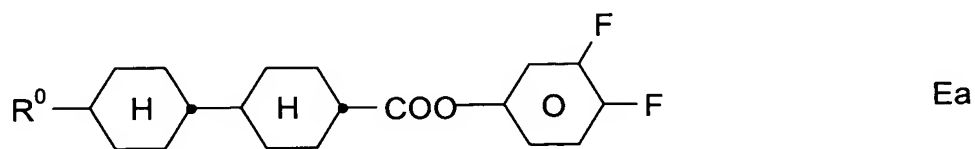


in which  $R^0$ ,  $X^0$ ,  $Y^1$  and  $Y^2$  are each, independently of one another, as defined in Claim 4.  $Y^3$  and  $Y^4$  are H or F.  $X^0$  is preferably F, Cl,  $CF_3$ ,  $OCF_3$  or  $OCHF_2$ .  $R^0$  is preferably alkyl, alkoxy, oxaalkyl, fluoroalkyl or alkenyl, each having up to 6 carbon atoms.

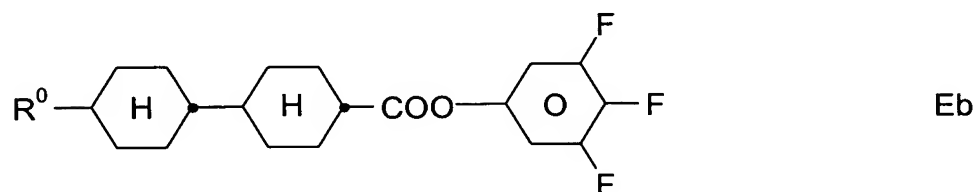
- The medium additionally comprises one or more ester compounds of the formulae Ea to Ee

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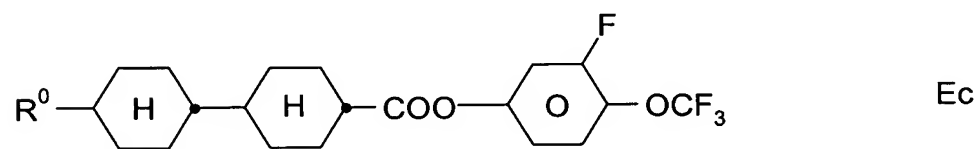
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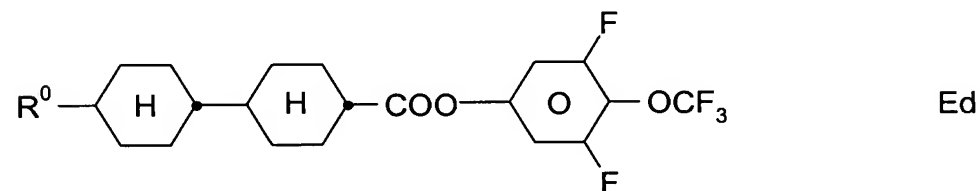
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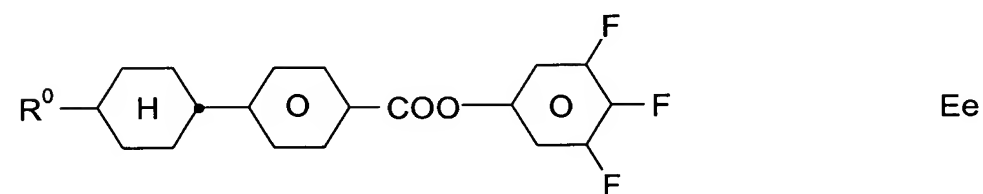
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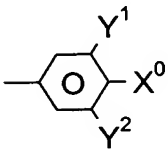
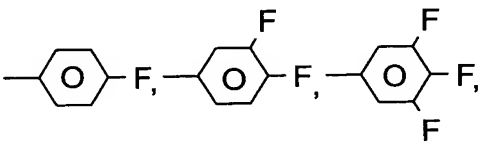
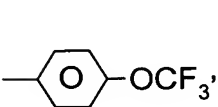
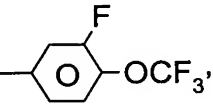
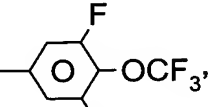
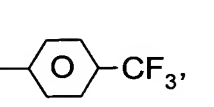
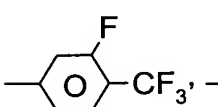
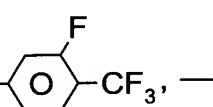
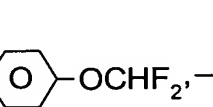
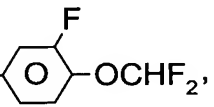
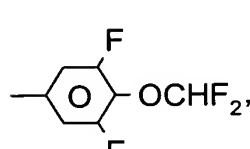
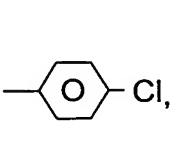
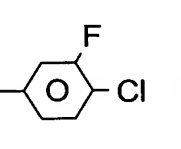
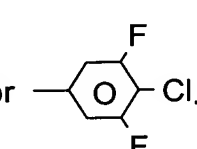
in which R<sup>0</sup> is as defined in Claim 4;

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- The proportion of the compounds of the formulae Ea to Ee is preferably 10-30% by weight, in particular 15-25% by weight;
- The proportion of compounds of the formulae IA and I to VI together in the mixture as a whole is at least 50% by weight;

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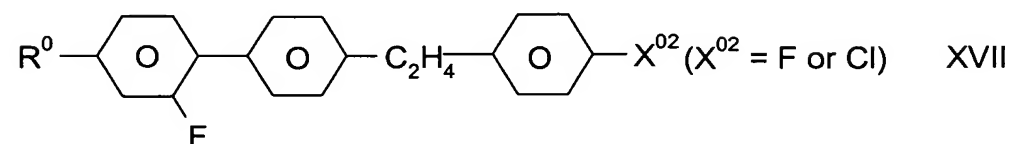
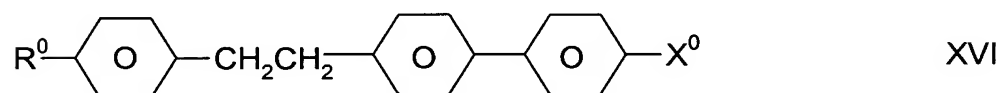
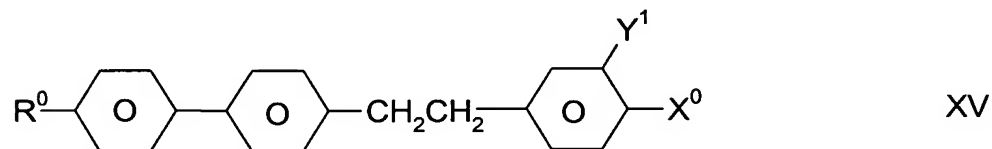
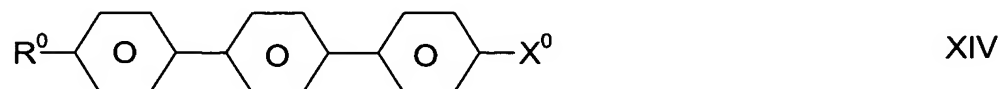
- 24 -

- The proportion of compounds of the formula I in the mixture as a whole is from 5 to 40% by weight, particularly preferably from 10 to 30% by weight;
- 5    - The proportion of compounds of the formula IA in the mixture as a whole is from 5 to 40% by weight, particularly preferably from 10 to 30% by weight;
- 10    - The proportion of compounds of the formulae II to VI in the mixture as a whole is from 30 to 80% by weight;
- 15    -  is preferably 
  




  




  



or

- 20    - The medium comprises compounds of the formula II, III, IV, V or VI;
- 25    -  $R^0$  is straight-chain alkyl or alkenyl having from 2 to 7 carbon atoms;
- 30    - The medium essentially consists of compounds of the formulae IA and I to VI;

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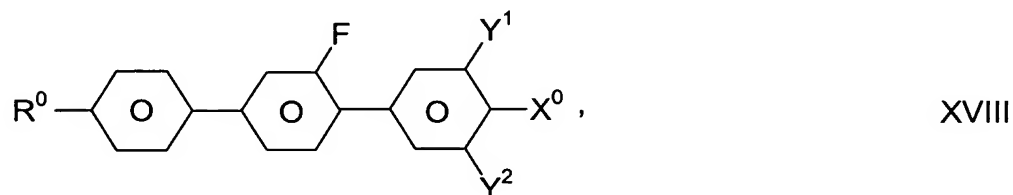


- The medium comprises further compounds, preferably selected from the following group consisting of the general formulae XIV to XVII:

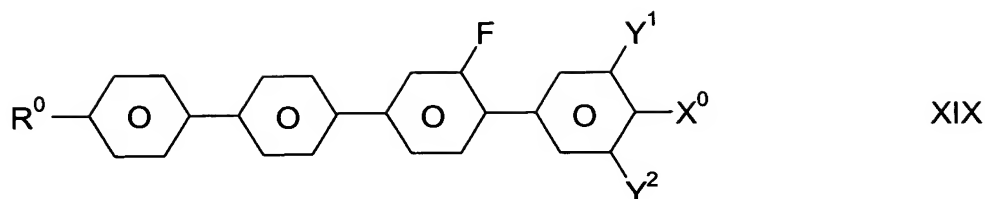


20 in which  $R^0$  and  $X^0$  are as defined above, and the 1,4-phenylene rings may be substituted by CN, chlorine or fluorine. The 1,4-phenylene rings are preferably monosubstituted or polysubstituted by fluorine atoms.

- The medium additionally comprises one or more compounds of the formulae XVIII and/or XIX



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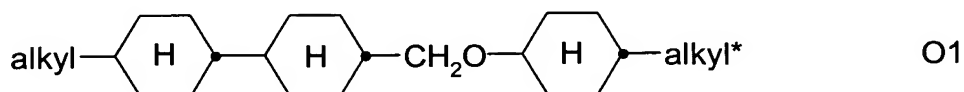


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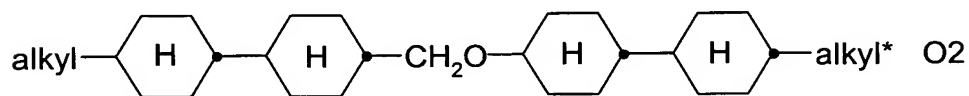
in which  $R^0$ ,  $X^0$ ,  $Y^1$  and  $Y^2$  are each, independently of one another a straight-chain or branched alkyl radical having 1 - 9 carbon atoms.

- The medium additionally comprises one, two, three or more, preferably two or three, compounds of the formulae

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in which "alkyl" and "alkyl\*" are as defined below.

The proportion of the compounds of the formulae O1 and/or O2 in the mixtures according to the invention is preferably 5-10% by weight.

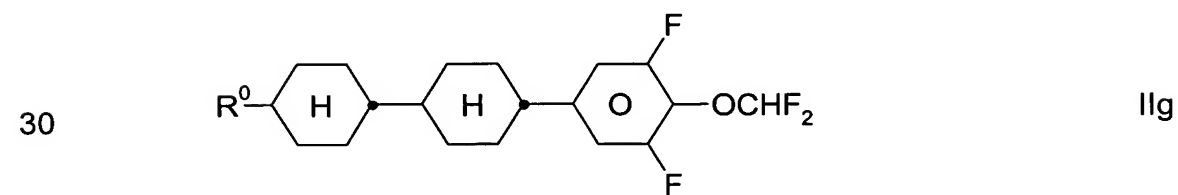
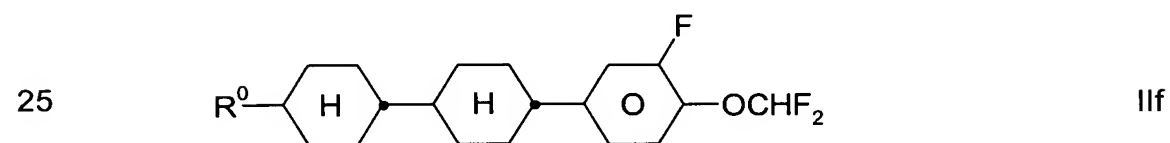
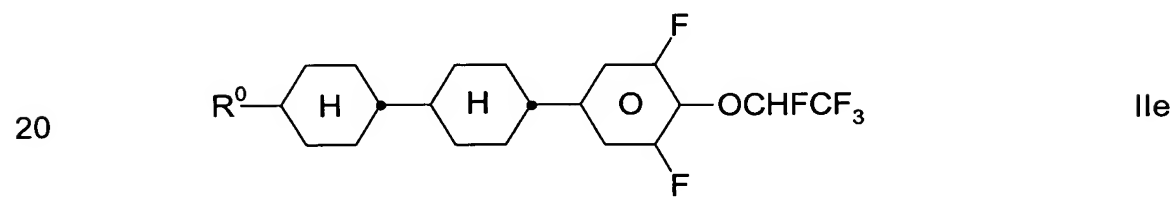
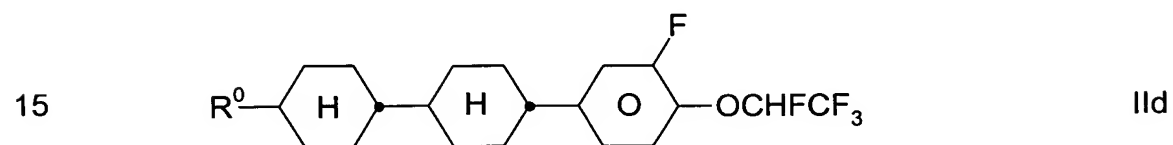
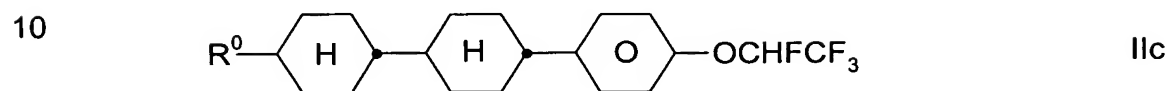
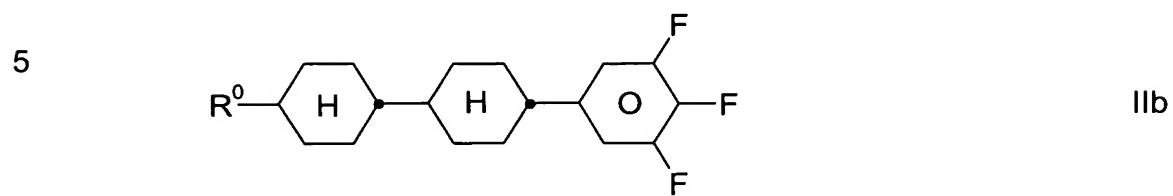
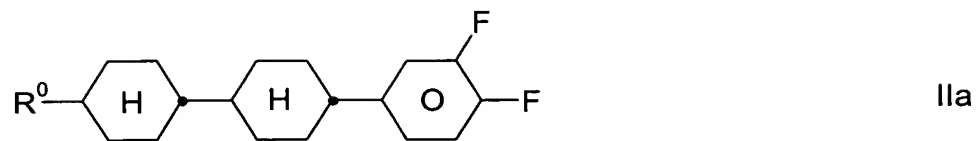
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- The medium preferably comprises 5-35% by weight of compound IVa.
- The medium preferably comprises one, two or three compounds of the formula IVa in which  $X^0$  is F or  $OCF_3$ .
- The medium preferably comprises one or more compounds of the formulae IIa to IIg

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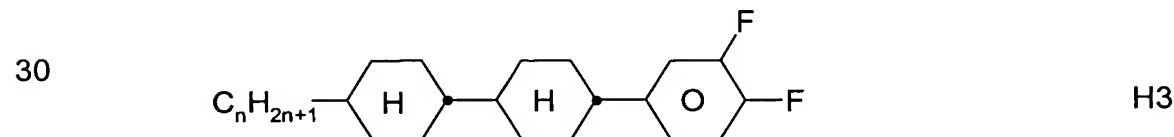
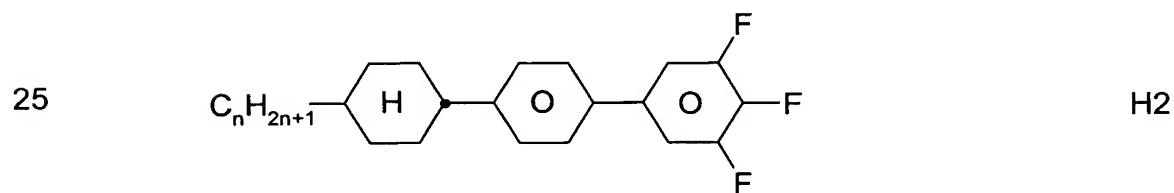
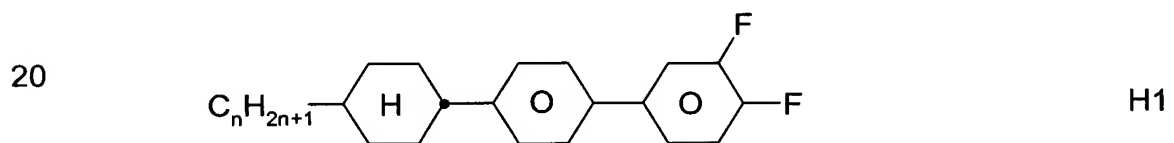
- 27 -



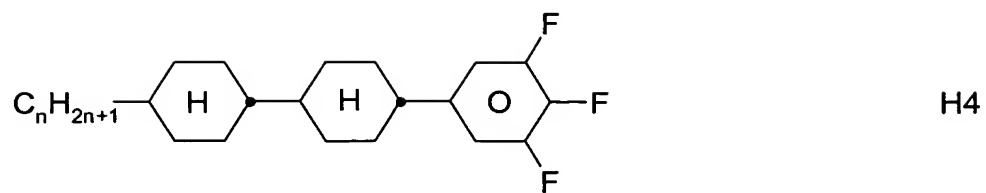
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in which  $R^0$  is as defined above. In the compounds of the formulae IIa-IIg,  $R^0$  is preferably H, methyl, ethyl, n-propyl, n-butyl or n-pentyl, furthermore n-hexyl or n-heptyl.

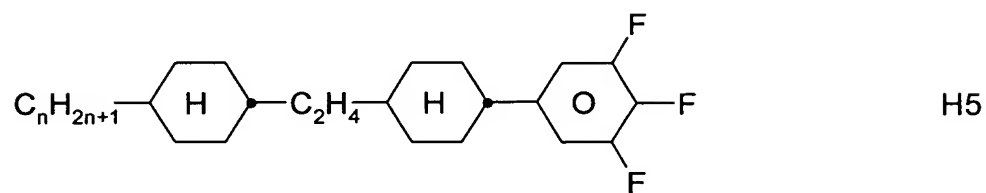
- 5      -      The (I + IA) : (II + III + IV + V + VI) weight ratio is preferably from 1 : 10 to 10 : 1.
- The medium essentially consists of compounds selected from the group consisting of the general formulae IA and I to XIII.
- 10     -      The proportion of the compounds of the formulae IVb and/or IVc in which  $X^0$  is fluorine and  $R^0$  is  $C_2H_5$ ,  $n-C_3H_7$ ,  $n-C_4H_9$  or  $n-C_5H_{11}$  in the mixture as a whole is from 2 to 20% by weight, in particular from 2 to 15% by weight;
- 15     -      The medium preferably comprises one, two or three, furthermore four, homologs of the compounds selected from the group consisting of H1 to H19 ( $n = 1-12$ ):



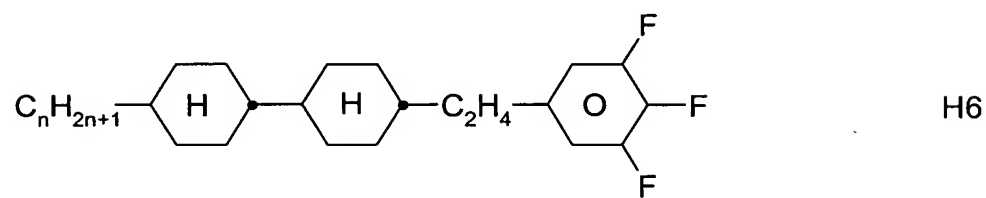
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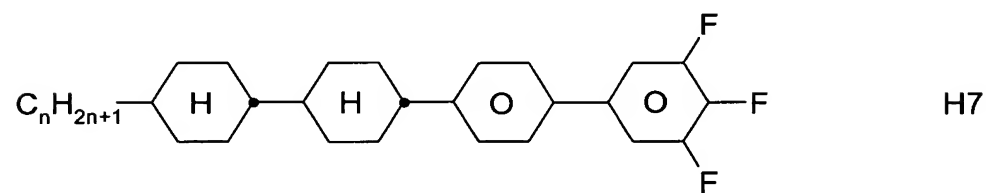
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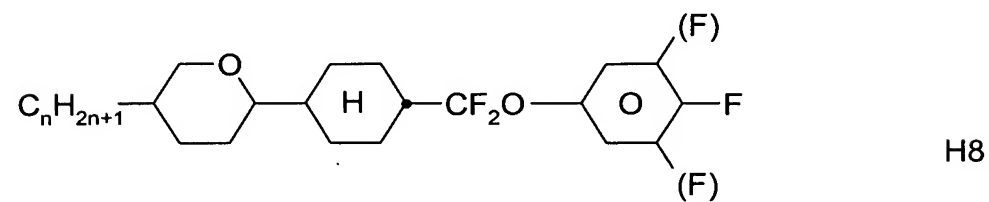
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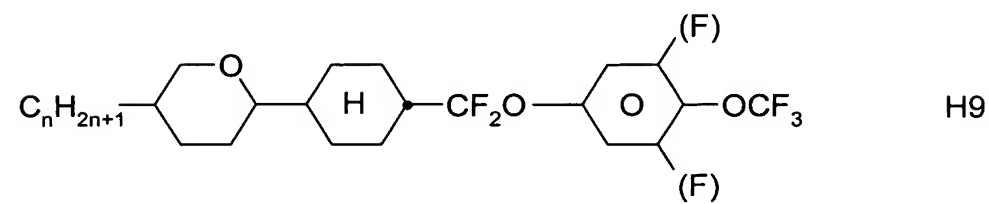
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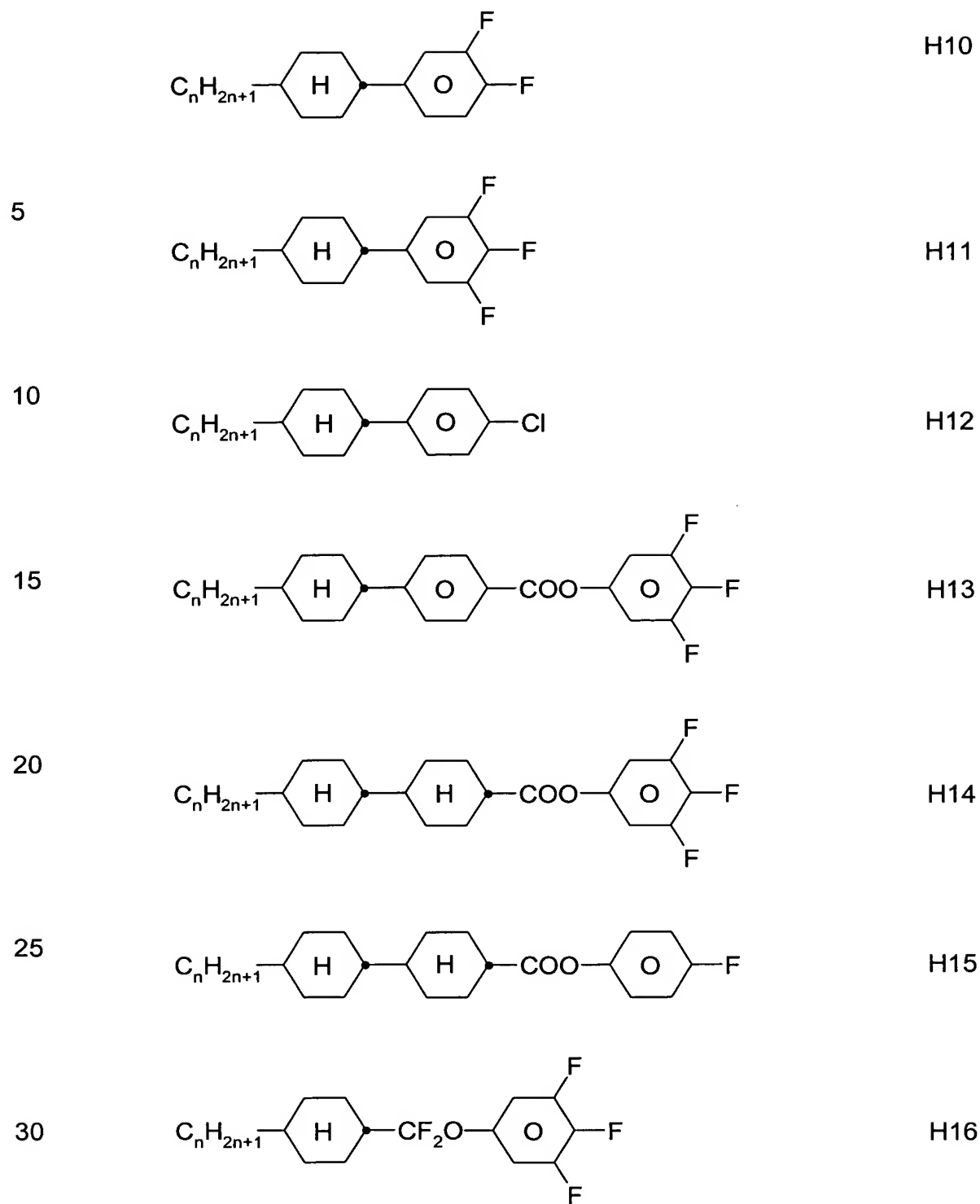
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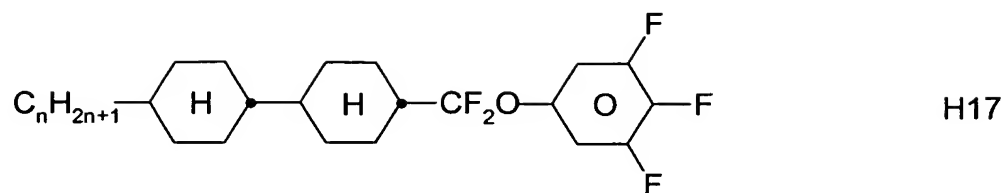
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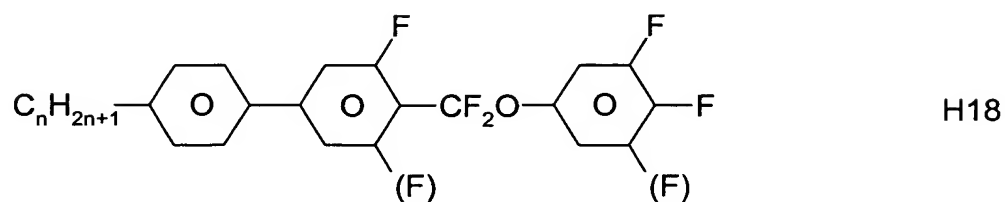


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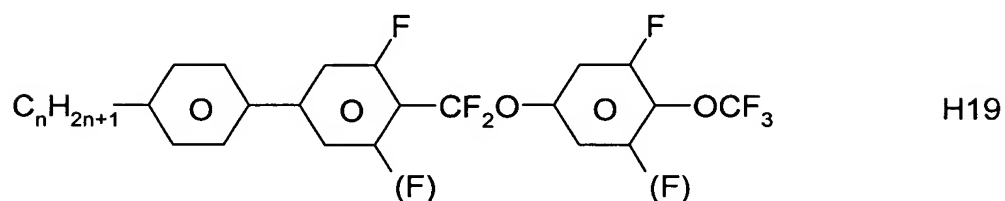
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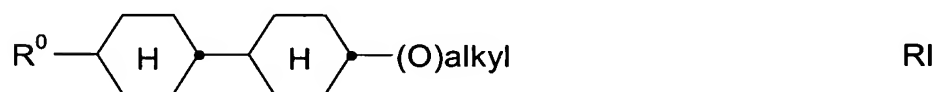
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- The medium preferably comprises the compound IIb in which R° is methyl;
- The medium comprises further compounds, preferably selected from the following group consisting of the formulae RI to RIX

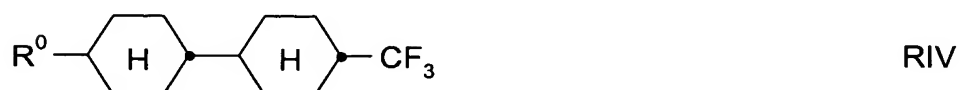
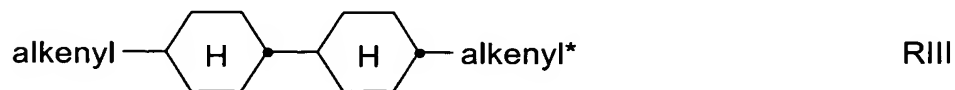
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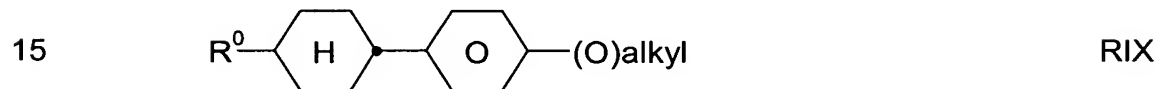
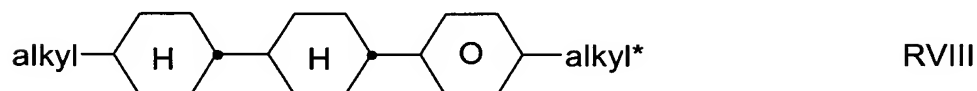
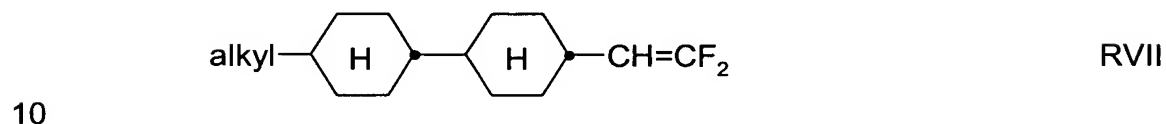
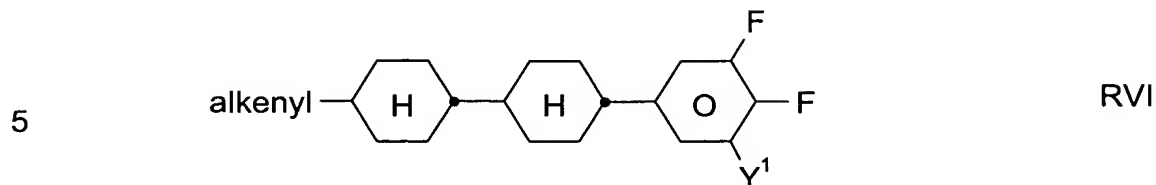
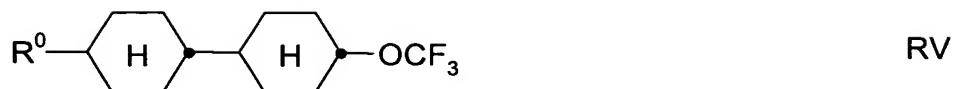


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- 32 -



in which

20
  $\text{R}^0$ 
 is n-alkyl, alkoxy, oxaalkyl, fluoroalkyl, alkenyloxy or alkenyl, each having up to 9 carbon atoms,

$\text{Y}^1$ 
 is H or F,

25
 alkyl and alkyl\* are each, independently of one another, a straight-chain or branched alkyl radical having 1-9 carbon atoms,

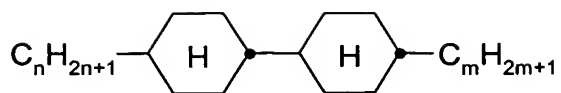
30
 alkenyl and alkenyl\* are each, independently of one another, a straight-chain or branched alkenyl radical having up to 9 carbon atoms.

- The medium preferably comprises one or more compounds of the formulae

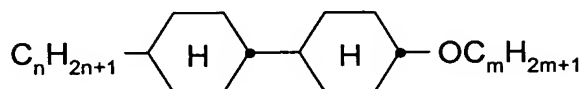
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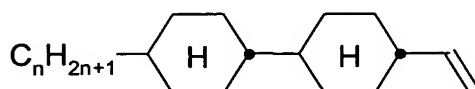
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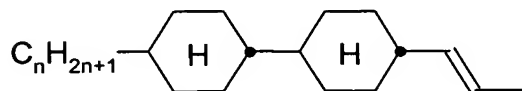
RIa



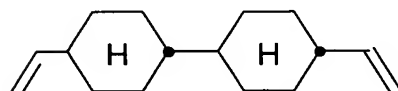
RIc



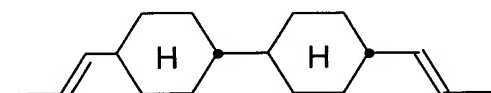
RIIa



RIIb



RIIIa

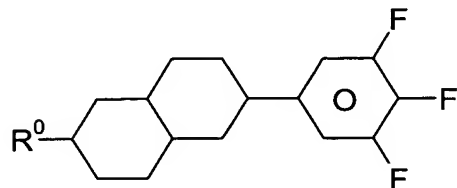


RIIIb

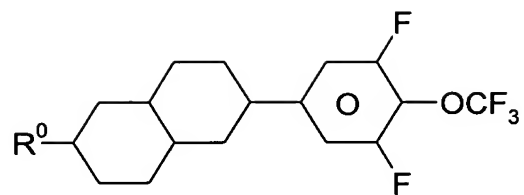
in which

$n$  and  $m$  are each 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12.  $n$  and  $m$  are preferably 1, 2, 3, 4, 5 or 6.

- The medium additionally comprises one, two or more compounds having fused rings, of the formulae AN1 to AN11:

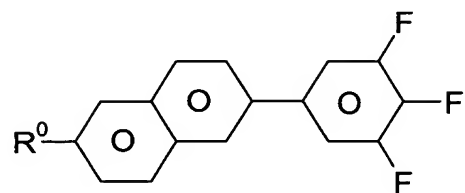


AN1



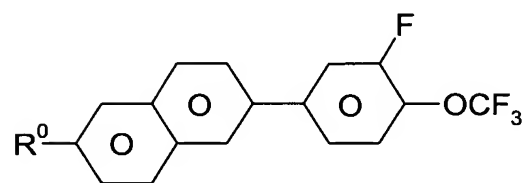
AN2

5



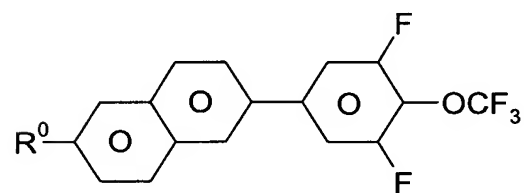
AN3

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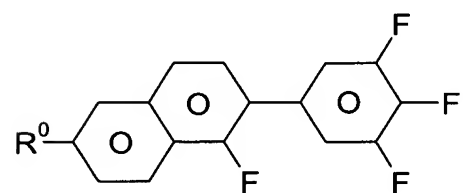
AN4

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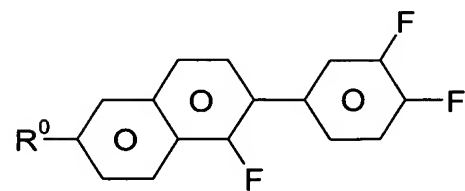
AN5

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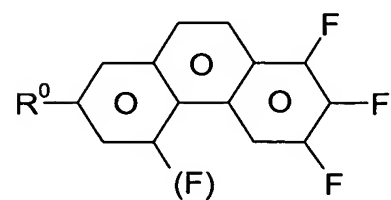
AN6

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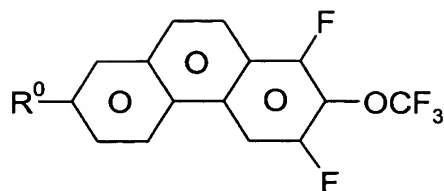
AN7

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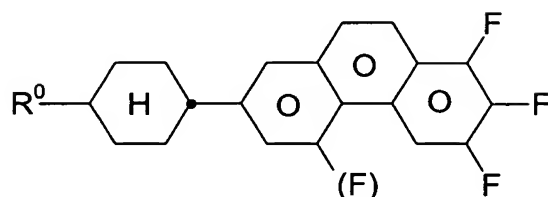
AN8

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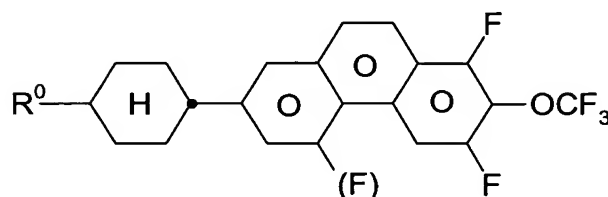
AN9

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AN10

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AN11

15

in which  $R^0$  is as defined above.

20

The term "alkyl" or "alkyl\*" covers straight-chain and branched alkyl groups having 1-7 carbon atoms, in particular the straight-chain groups methyl, ethyl, propyl, butyl, pentyl, hexyl and heptyl. Groups having 2-5 carbon atoms are generally preferred.

25

30

The term "alkenyl" covers straight-chain and branched alkenyl groups having 2-7 carbon atoms, in particular the straight-chain groups. Preferred alkenyl groups are  $C_2$ - $C_7$ -1E-alkenyl,  $C_4$ - $C_7$ -3E-alkenyl,  $C_5$ - $C_7$ -4-alkenyl,  $C_6$ - $C_7$ -5-alkenyl and  $C_7$ -6-alkenyl, in particular  $C_2$ - $C_7$ -1E-alkenyl,  $C_4$ - $C_7$ -3E-alkenyl and  $C_5$ - $C_7$ -4-alkenyl. Examples of particularly preferred alkenyl groups are vinyl, 1E-propenyl, 1E-butenyl, 1E-pentenyl, 1E-hexenyl, 1E-heptenyl, 3-butenyl, 3E-pentenyl, 3E-hexenyl, 3E-heptenyl, 4-pentenyl, 4Z-hexenyl, 4E-hexenyl, 4Z-heptenyl, 5-hexenyl, 6-heptenyl and the like. Groups having up to 5 carbon atoms are generally preferred.

35

The term "fluoroalkyl" preferably covers straight-chain groups having a terminal fluorine, i.e. fluoromethyl, 2-fluoroethyl, 3-fluoropropyl, 4-fluorobutyl, 5-fluoropentyl, 6-fluorohexyl and 7-fluoroheptyl. However, other positions of the fluorine are not excluded.

The term "oxaalkyl" preferably covers straight-chain radicals of the formula  $C_nH_{2n+1}-O-(CH_2)_m$ , in which  $n$  is from 1 to 6 and  $m$  is from 0 to 6. Preferably,  $n = 1$  or  $2$  and  $m$  is from 0 to 6.

5 It has been found that even a relatively small proportion of compounds of the formulae I and IA mixed with conventional liquid-crystal materials, but in particular with one or more compounds of the formulae II, III, IV, V and/or VI, results in a significant lowering of the threshold voltage and in  
10 high values for the VHR (100°C), with broad nematic phases with low smectic-nematic transition temperatures being observed at the same time, improving the shelf life. Preference is given, in particular, to mixtures which, besides one or more compounds of the formulae I and IA, comprise one or more compounds of the formula IV, in particular compounds of the  
15 formula IVa in which  $X^0$  is F or  $OCF_3$ . The compounds of the formulae IA and I to VI are colourless, stable and readily miscible with one another and with other liquid-crystalline materials.

Through a suitable choice of the meanings of  $R^0$  and  $X^0$ , the addressing times, the threshold voltage, the steepness of the transmission characteristic lines, etc., can be modified in the desired manner. For example, 1E-  
20 alkenyl radicals, 3E-alkenyl radicals, 2E-alkenyloxy radicals and the like generally result in shorter addressing times, improved nematic tendencies and a higher ratio of the elastic constants  $k_{33}$  (bend) and  $k_{11}$  (splay) compared with alkyl or alkoxy radicals. 4-alkenyl radicals, 3-alkenyl radicals  
25 and the like generally give lower threshold voltages and smaller values of  $k_{33}/k_{11}$  compared with alkyl and alkoxy radicals.

A  $-CH_2CH_2-$  group generally results in higher values of  $k_{33}/k_{11}$  compared with a single covalent bond. Higher values of  $k_{33}/k_{11}$  facilitate, for example,  
30 flatter transmission characteristic lines in TN cells with a 90° twist (in order to achieve grey shades) and steeper transmission characteristic lines in STN, SBE and OMI cells (greater multiplexability), and vice versa.

The optimum mixing ratio of the compounds of the formulae I, IA and II +  
35 III + IV + V + VI depends substantially on the desired properties, on the

choice of the components of the formulae I, IA, II, III, IV, V and/or VI, and on the choice of any other components that may be present. Suitable mixing ratios within the range given above can easily be determined from case to case.

5 The total amount of compounds of the formulae IA and I to XIII in the mixtures according to the invention is not crucial. The mixtures can therefore comprise one or more further components for the purposes of optimisation of various properties. However, the observed effect on the addressing times and the threshold voltage is generally greater, the higher  
10 the total concentration of compounds of the formulae IA and I to XIII.

In a particularly preferred embodiment, the media according to the invention comprise compounds of the formulae II to VI (preferably II, III and/or IV, in particular IVa) in which  $X^0$  is F,  $OCF_3$ ,  $OCHF_2$ , F,  $OCH=CF_2$ ,  
15  $OCF=CF_2$  or  $OCF_2-CF_2H$ . A favourable synergistic effect with the compounds of the formulae I and IA results in particularly advantageous properties. In particular, mixtures comprising compounds of the formula I, IA and of the formula IVa are distinguished by their low threshold voltages.

20 The individual compounds of the formulae IA and I to XVIII and their subformulae which can be used in the media according to the invention are either known or can be prepared analogously to the known compounds.

25 The construction of the MLC display according to the invention from polarisers, electrode base plates and surface-treated electrodes corresponds to the conventional construction for displays of this type. The term conventional construction is broadly drawn here and also covers all derivatives and modifications of the MLC display, in particular including matrix display elements based on poly-Si TFT or MIM.

30 A significant difference between the displays according to the invention and the conventional displays based on the twisted nematic cell consists, however, in the choice of the liquid-crystal parameters of the liquid-crystal layer.  
35

The liquid-crystal mixtures which can be used in accordance with the invention are prepared in a manner conventional per se. In general, the desired amount of the components used in the lesser amount is dissolved in the components making up the principal constituent, advantageously at elevated temperature. It is also possible to mix solutions of the components in an organic solvent, for example in acetone, chloroform or methanol, and to remove the solvent again, for example by distillation, after thorough mixing.

The dielectrics may also comprise further additives known to the person skilled in the art and described in the literature, such as, for example, stabilisers, UV filters and antioxidants. For example, 0-15% of pleochroic dyes or chiral dopants can be added.

C denotes a crystalline phase, S a smectic phase,  $S_C$  a smectic C phase, N a nematic phase and I the isotropic phase.

$V_{10}$  denotes the voltage for 10% transmission (viewing angle perpendicular to the plate surface).  $t_{on}$  denotes the switch-on time and  $t_{off}$  the switch-off time at an operating voltage corresponding to 2.0 times the value of  $V_{10}$ .  $\Delta n$  denotes the optical anisotropy.  $\Delta\epsilon$  denotes the dielectric anisotropy ( $\Delta\epsilon = \epsilon_{||} - \epsilon_{\perp}$ , where  $\epsilon_{||}$  denotes the dielectric constant parallel to the longitudinal molecular axes and  $\epsilon_{\perp}$  denotes the dielectric constant perpendicular thereto). The electro-optical data are measured in a TN cell at the 1st minimum (i.e. at a  $d \cdot \Delta n$  value of  $0.5 \mu m$ ) at  $20^\circ C$ , unless expressly stated otherwise. The optical data are measured at  $20^\circ C$ , unless expressly stated otherwise.

In the present application and in the examples below, the structures of the liquid-crystal compounds are indicated by means of acronyms, the transformation into chemical formulae taking place in accordance with Tables A and B below. All radicals  $C_nH_{2n+1}$  and  $C_mH_{2m+1}$  are straight-chain alkyl radicals having  $n$  and  $m$  carbon atoms respectively;  $n$  and  $m$  are integers and are preferably 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12. The coding in Table B is self-evident. In Table A, only the acronym for the parent structure is indicated. In individual cases, the acronym for the parent structure is

- 39 -

followed, separated by a dash, by a code for the substituents  $R^{1*}$ ,  $R^{2*}$ ,  $L^{1*}$ ,  $L^{2*}$  and  $L^{3*}$ :

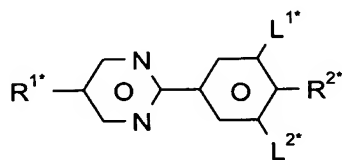
	Code for $R^{1*}$ , $R^{2*}$ , $L^{1*}$ , $L^{2*}$ , $L^{3*}$	$R^{1*}$	$R^{2*}$	$L^{1*}$	$L^{2*}$	$L^{3*}$
5						
	nm	$C_nH_{2n+1}$	$C_mH_{2m+1}$	H	H	H
	nOm	$OC_nH_{2n+1}$	$C_mH_{2m+1}$	H	H	H
	nO.m	$C_nH_{2n+1}$	$OC_mH_{2m+1}$	H	H	H
10	n	$C_nH_{2n+1}$	CN	H	H	H
	nN.F	$C_nH_{2n+1}$	CN	H	H	F
	nN.F.F	$C_nH_{2n+1}$	CN	H	F	F
	nF	$C_nH_{2n+1}$	F	H	H	H
15	nOF	$OC_nH_{2n+1}$	F	H	H	H
	nF.F	$C_nH_{2n+1}$	F	H	H	F
	nmF	$C_nH_{2n+1}$	$C_mH_{2m+1}$	F	H	H
	nOCF <sub>3</sub>	$C_nH_{2n+1}$	OCF <sub>3</sub>	H	H	H
	nOCF <sub>3</sub> .F	$C_nH_{2n+1}$	OCF <sub>3</sub>	F	H	H
20	n-Vm	$C_nH_{2n+1}$	$-CH=CH-C_mH_{2m+1}$	H	H	H
	nV-Vm	$C_nH_{2n+1}-CH=CH-$	$-CH=CH-C_mH_{2m+1}$	H	H	H

Preferred mixture components are given in Tables A and B.

25

**Table A:**

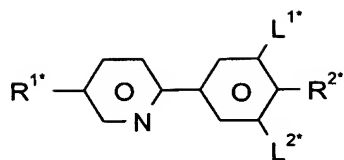
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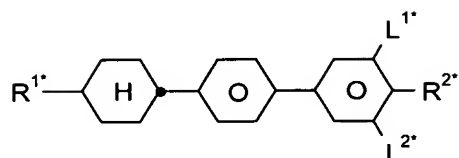
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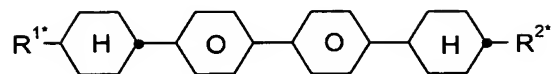
**PYRP**

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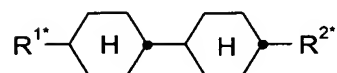
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**BCH**



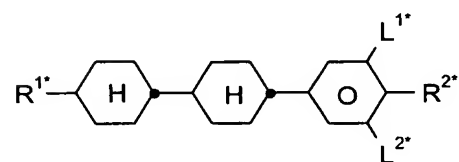
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**CBC**



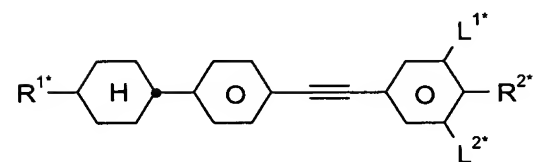
**CCH**

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25

**CCP**



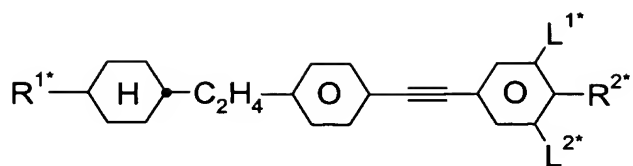
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**CPTP**

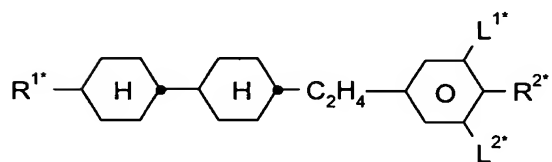
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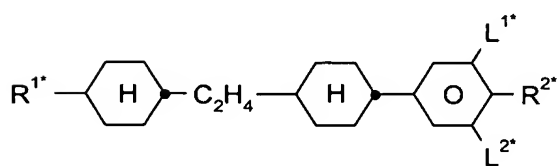
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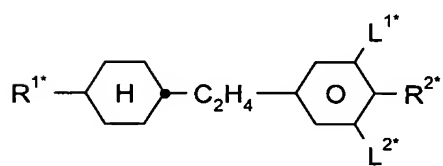
5 **CEPT**



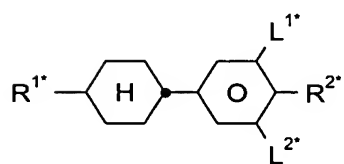
10 **ECCP**



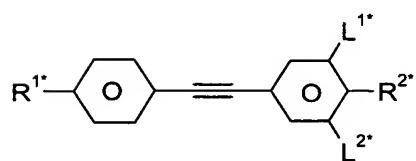
15 **CECF**



20 **EPCH**



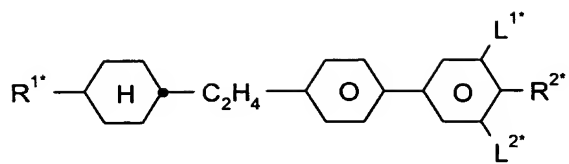
25 **PCH**



30 **PTP**

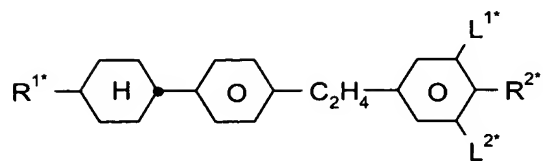
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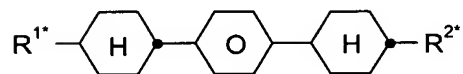
**BECH**

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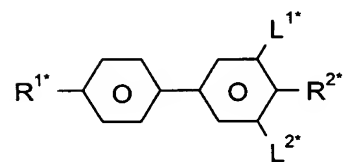
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**EBCH**



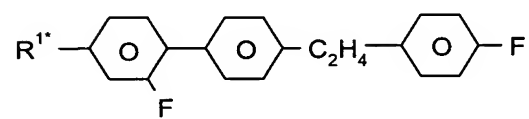
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**CPC**



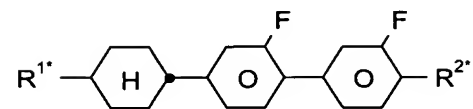
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**B**



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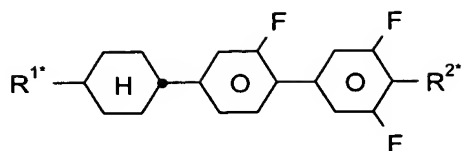
**FET-n-F**



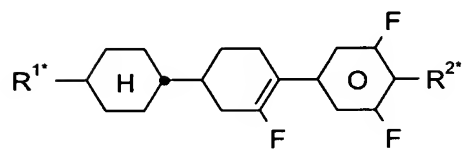
30

**CGG**

35

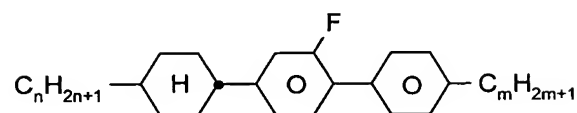


**CGU**

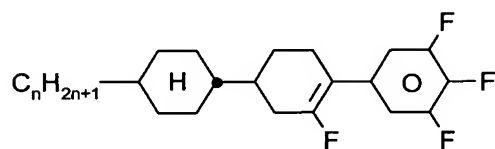


**CFU**

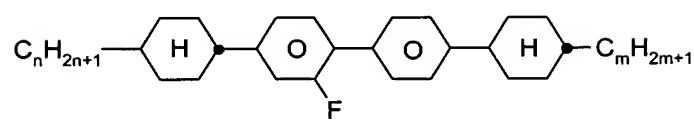
**Table B:**



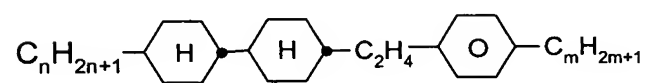
**BCH-n.Fm**



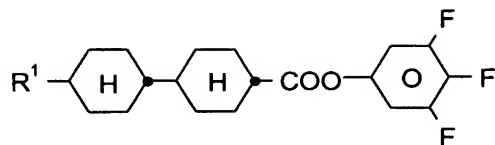
**CFU-n-F**



**CBC-nmF**

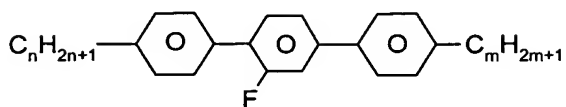


**ECCP-nm**



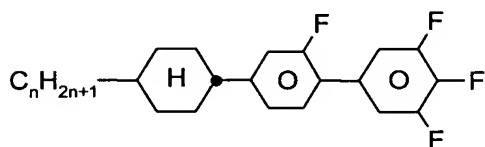
**CCZU-n-F**

5



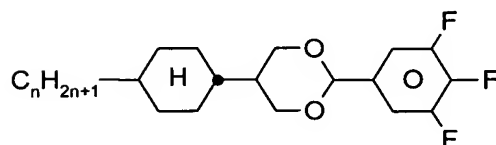
**T-nFm**

10



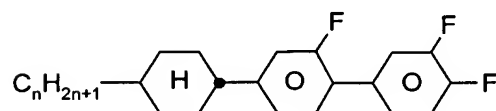
**CGU-n-F**

15



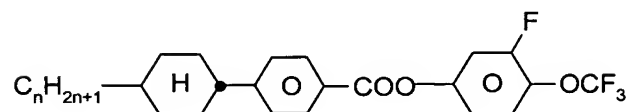
**CDU-n-F**

20



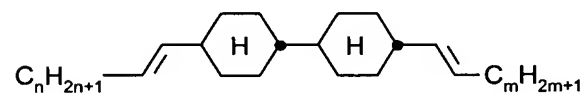
**CGG-n-F**

25



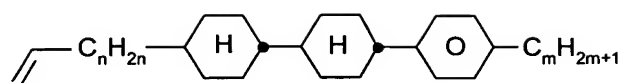
**CPZG-n-OT**

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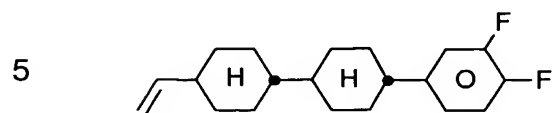


**CC-nV-Vm**

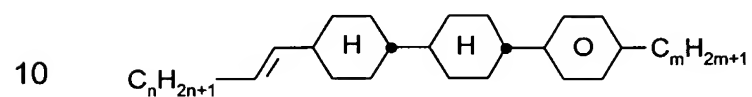
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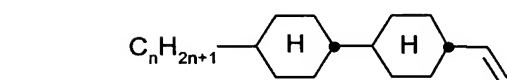
**CCP-Vn-m**



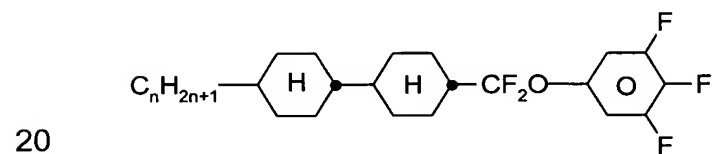
**CCG-V-F**



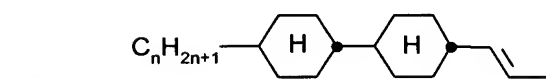
**CCP-nV-m**



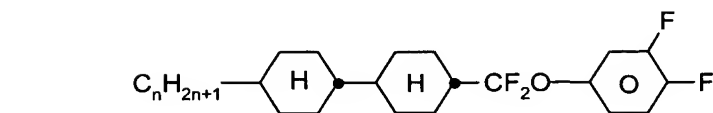
**CC-n-V**



**CCQU-n-F**

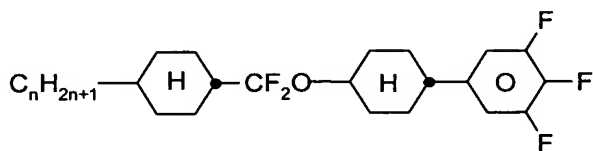


**CC-n-V1**

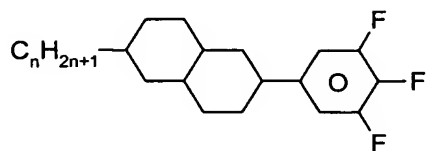


**CCQG-n-F**

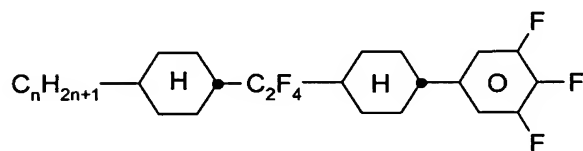
- 46 -



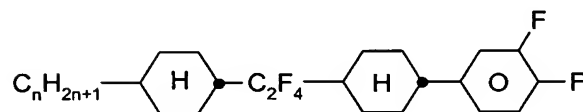
**CQCU-n-F**



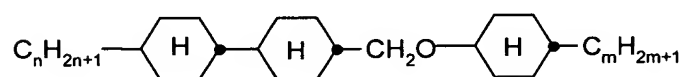
**Dec-U-n-F**



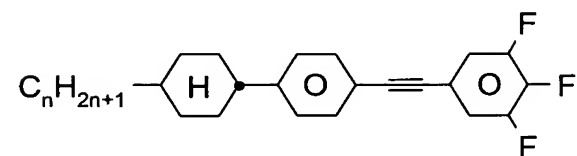
**CWCU-n-F**



**CWCG-n-F**



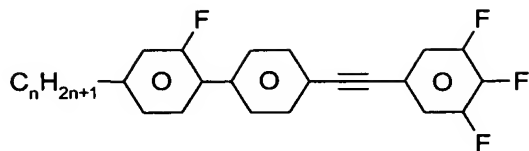
**CCOC-n-m**



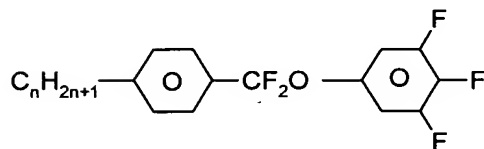
**CPTU-n-F**

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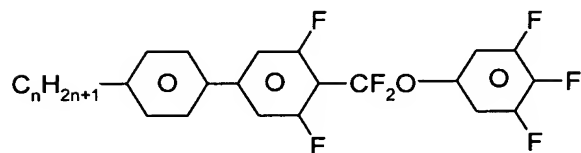
- 47 -



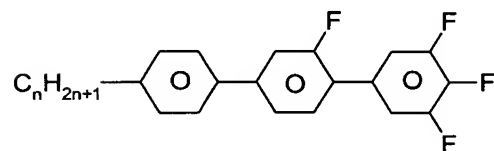
5 **GPTU-n-F**



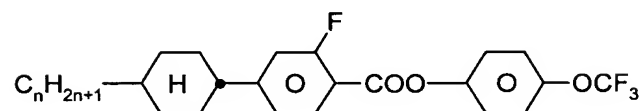
10 **PQU-n-F**



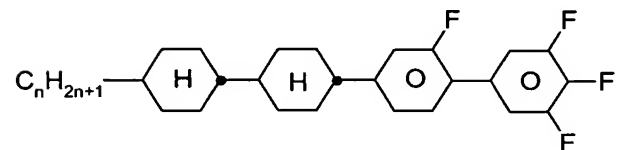
15 **PUQU-n-F**



20 **PGU-n-F**



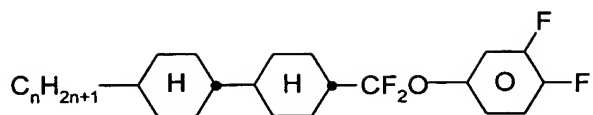
25 **CGZP-n-OT**



30 **CCGU-n-F**

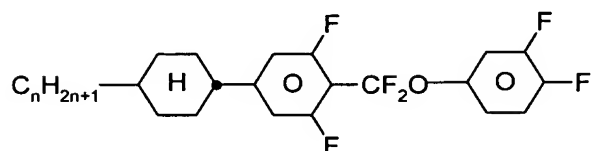
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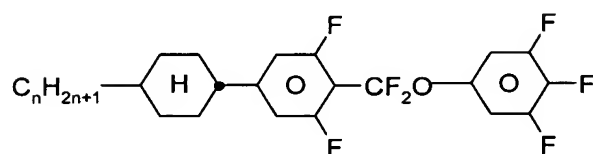
**CCQG-n-F**

5



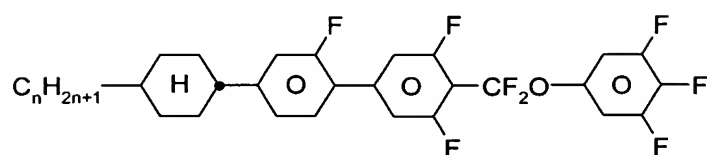
**CUQG-n-F**

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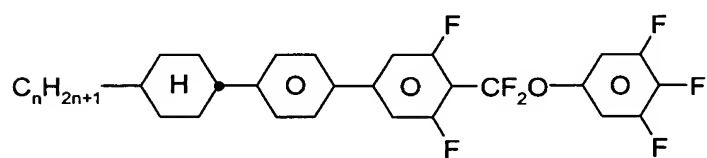
**CUQU-n-F**

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**CGUQU-n-F**

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**CPUQU-n-F**

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Particular preference is given to liquid-crystalline mixtures which, besides the compounds of the formulae I and IA, comprise at least one, two, three or four compounds from Table B.

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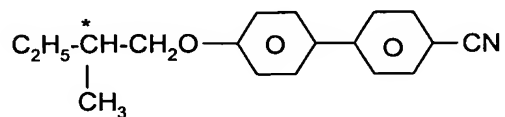
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**Table C:**

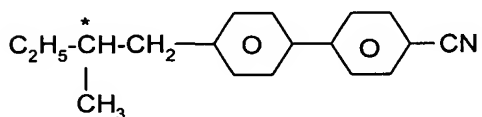
Table C shows possible dopants which are generally added to the mixtures according to the invention.

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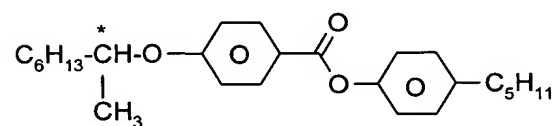
**C 15**

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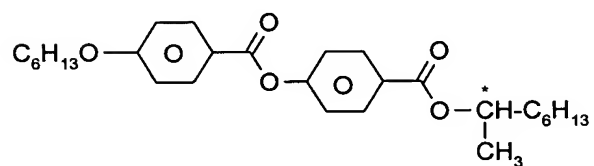
**CB 15**

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**CM 21**

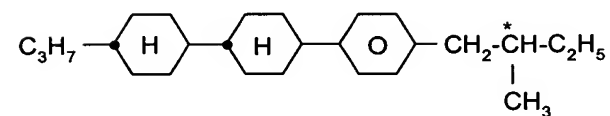
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**R/S-811**

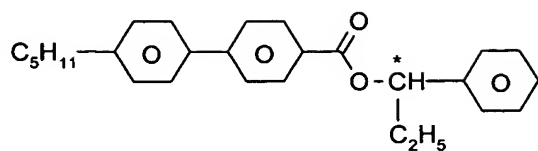
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**CM 44**

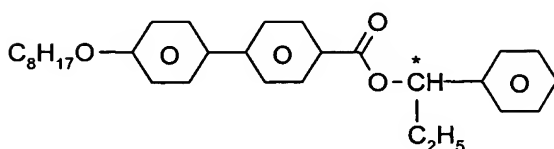
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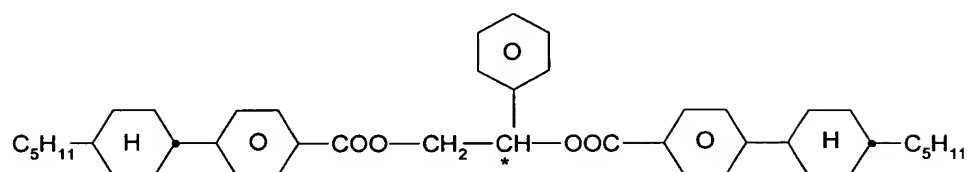
**CM 45**

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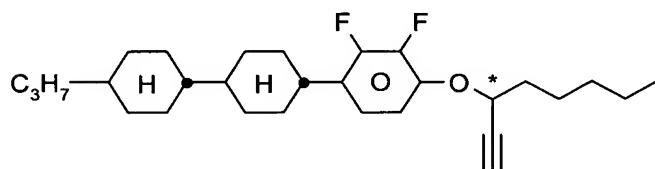
**CM 47**

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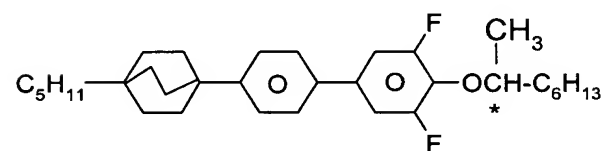
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**R/S-1011**



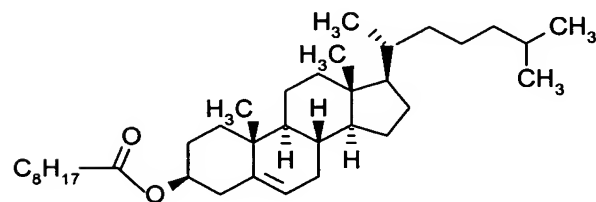
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**R/S-3011**



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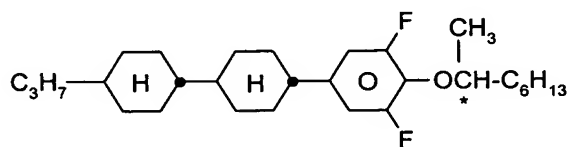
**R/S-4011**



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**CN**

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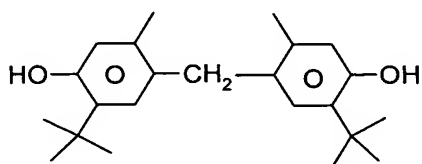
**R/S-2011**

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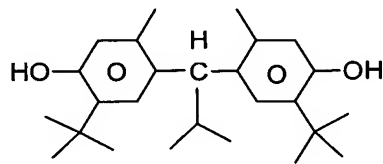
**Table D**

Stabilisers which can be added, for example, to the mixtures according to the invention are mentioned below.

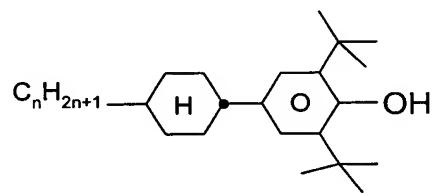
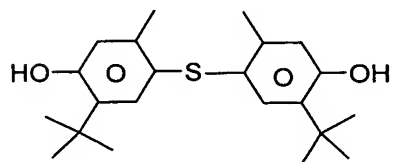
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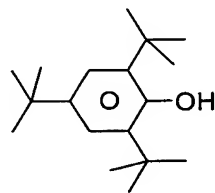
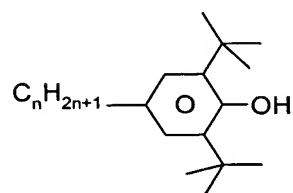
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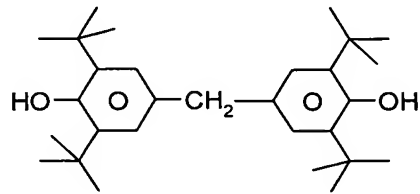
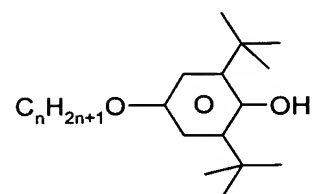
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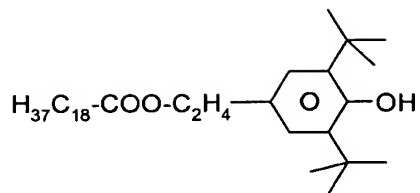
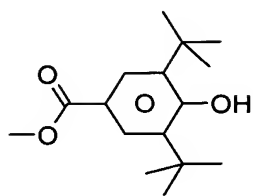
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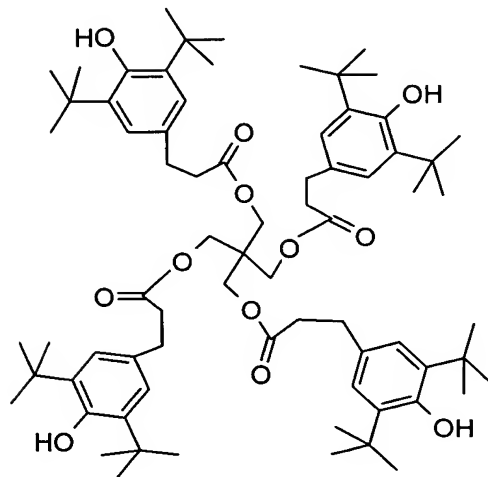
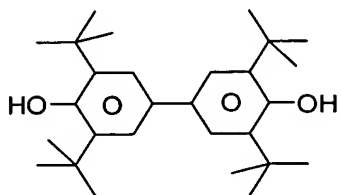
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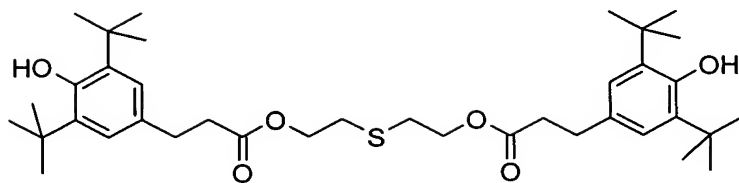


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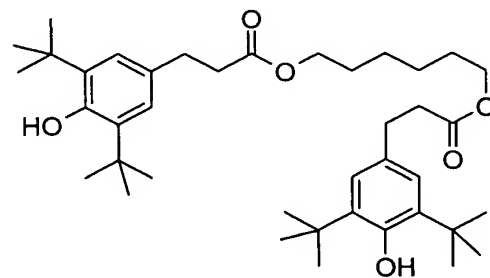
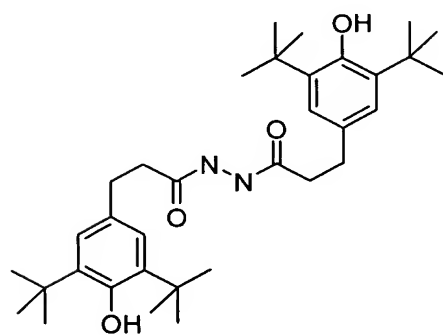


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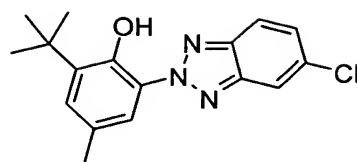
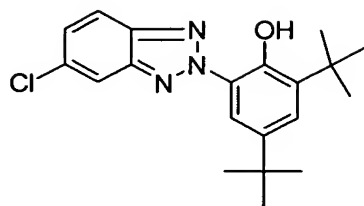


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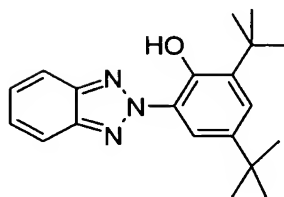
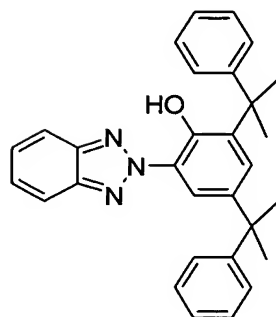
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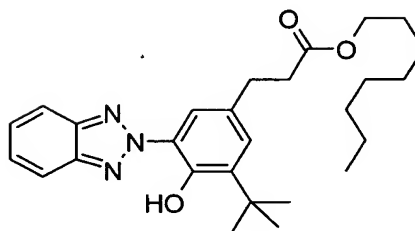
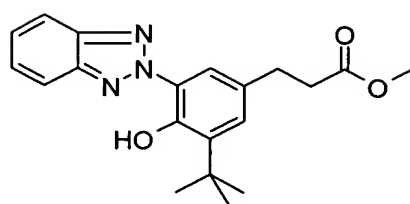
- 54 -



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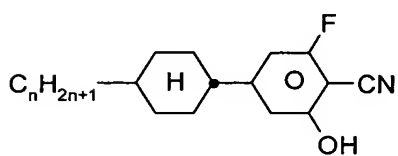


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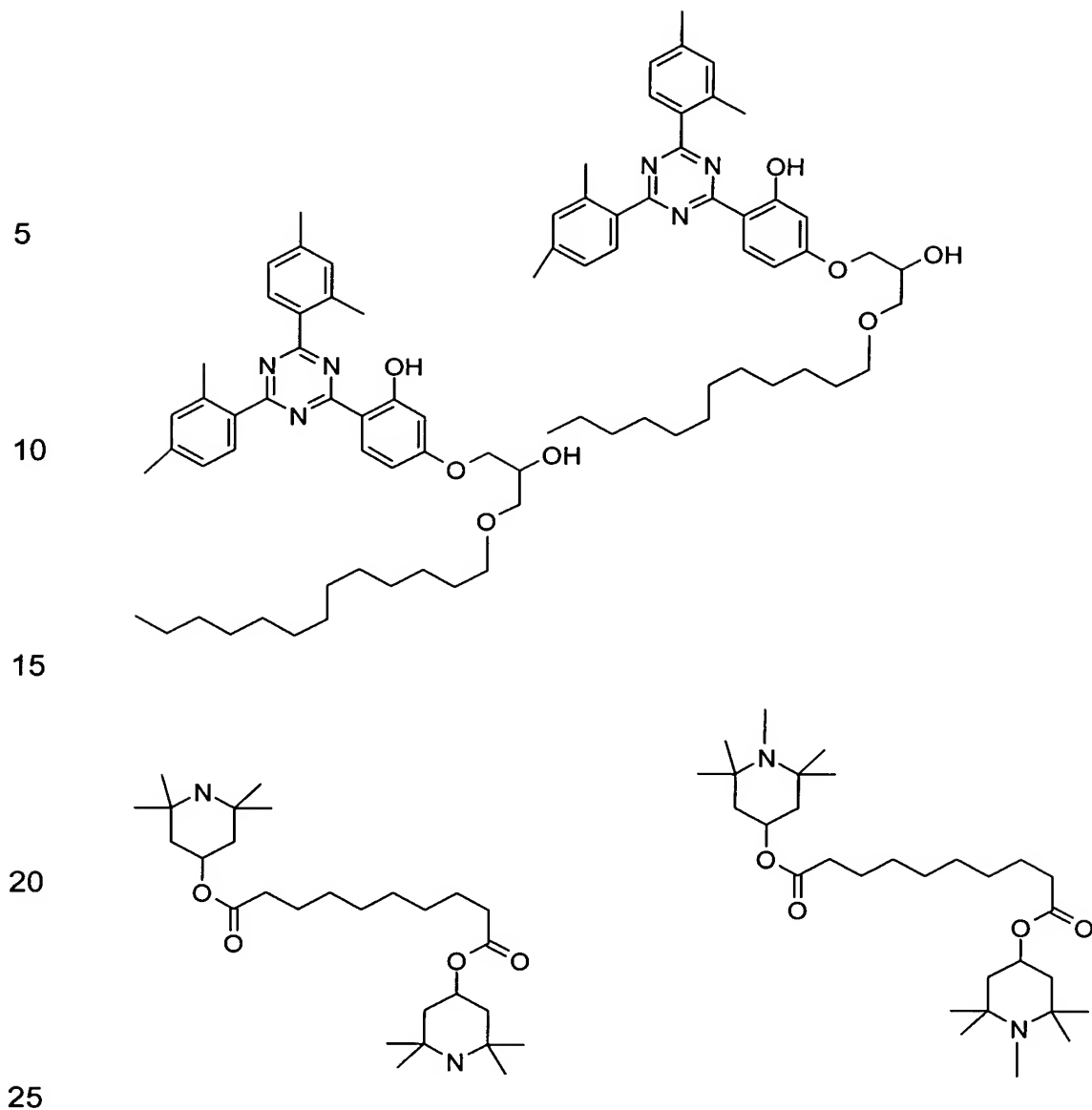


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The following examples are intended to explain the invention without restricting it. Above and below, percentages are per cent by weight. All temperatures are given in degrees Celsius. m.p. denotes melting point, cl.p. clearing point. Furthermore, C = crystalline state, N = nematic phase, S = smectic phase and I = isotropic phase. The data between these symbols represent the transition temperatures.  $\Delta n$  denotes optical anisotropy (589 nm, 20°C),  $\Delta\epsilon$  the dielectric anisotropy (1 kHz, 20°C), and the flow viscosity  $\eta_{20}$  (mm<sup>2</sup>/sec) was determined at 20°C. The rotational viscosity  $\gamma_1$  (mPa·s) was likewise determined at 20°C.

Example M1

5	CCP-1F.F.F	10.00 %	S → N [°C]:	< -40.0
	CCP-2F.F.F	10.00 %	Clearing point [°C]:	+84.0
	CCP-20CF <sub>3</sub>	7.00 %	Δn [589 nm; 20°C]:	+0.0944
	CCP-30CF <sub>3</sub>	8.00 %	γ <sub>1</sub> [mPa·s; 20°C]:	113
	CCP-40CF <sub>3</sub>	6.00 %	d · Δn [20°C; μm]:	0.50
10	CCP-50CF <sub>3</sub>	3.00 %	Twist [°]:	90
	PGU-2-F	5.00 %	V <sub>10</sub> [V]:	1.28
	PGU-3-F	2.00 %		
	CGUQU-2-F	10.00 %		
	CGUQU-3-F	10.00 %		
15	CCG-V-F	4.00 %		
	CCH-35	5.00 %		
	CC-3-V1	11.00 %		
	CC-5-V	9.00 %		

Example M2

20	CCP-1F.F.F	10.00 %	S → N [°C]:	< -40.0
	CCP-2F.F.F	10.00 %	Clearing point [°C]:	+84.0
	CCP-3F.F.F	4.00 %	Δn [589 nm; 20°C]:	+0.0944
	CCP-20CF <sub>3</sub>	6.00 %	γ <sub>1</sub> [mPa·s; 20°C]:	116
	CCP-30CF <sub>3</sub>	8.00 %	d · Δn [20°C; μm]:	0.50
25	CCP-40CF <sub>3</sub>	6.00 %	Twist [°]:	90
	CCP-50CF <sub>3</sub>	4.00 %	V <sub>10</sub> [V]:	1.27
	PGU-2-F	5.00 %		
	PGU-3-F	12.00 %		
	CGUQU-2-F	10.00 %		
30	CGUQU-3-F	10.00 %		
	CCH-35	5.00 %		
	CC-3-V1	11.00 %		
	CC-5-V	9.00 %		



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Example M3

5	CCP-2F.F.F	7.00 %	S → N [°C]:	< -40.0
	CCP-20CF <sub>3</sub>	8.00 %	Clearing point [°C]:	+84.0
	CCP-30CF <sub>3</sub>	8.00 %	Δn [589 nm; 20°C]:	+0.0925
	CCP-40CF <sub>3</sub>	6.00 %	γ <sub>1</sub> [mPa·s; 20°C]:	115
	CCP-50CF <sub>3</sub>	4.00 %	d · Δn [20°C; μm]:	0.50
10	PGU-2-F	7.00 %	Twist [°]:	90
	CDU-2-F	10.00 %	V <sub>10</sub> [V]:	1.25
	CDU-3-F	7.00 %		
	CGUQU-2-F	8.00 %		
	CGUQU-3-F	10.00 %		
15	CCH-35	5.00 %		
	CC-3-V1	10.00 %		
	CC-5-V	10.00 %		

Example M4

20	CCP-1F.F.F	11.00 %	S → N [°C]:	< -40.0
	CCP-2F.F.F	10.00 %	Clearing point [°C]:	+83.5
	CCP-20CF <sub>3</sub> .F	10.50 %	Δn [589 nm; 20°C]:	+0.0937
	CCP-20CF <sub>3</sub>	8.00 %	γ <sub>1</sub> [mPa·s; 20°C]:	133
	CCP-30CF <sub>3</sub>	8.00 %	d · Δn [20°C; μm]:	0.50
25	CCP-40CF <sub>3</sub>	6.00 %	Twist [°]:	90
	CGU-2-F	10.00 %	V <sub>10</sub> [V]:	1.21
	CCGU-3-F	2.00 %		
	PGU-2-F	1.00 %		
	CPUQU-2-F	9.00 %		
30	CPUQU-3-F	9.00 %		
	CCH-35	5.00 %		
	CC-3-V1	10.50 %		

Example M5

5	CCP-1F.F.F	10.00 %	S → N [°C]:	< -40.0
	CCP-2F.F.F	8.00 %	Clearing point [°C]:	+85.5
	CCP-20CF <sub>3</sub> .F	12.00 %	Δn [589 nm; 20°C]:	+0.0930
	CCP-30CF <sub>3</sub> .F	8.00 %	γ <sub>1</sub> [mPa·s; 20°C]:	138
	CCP-20CF <sub>3</sub>	8.00 %	d · Δn [20°C; μm]:	0.50
	CCP-30CF <sub>3</sub>	8.00 %	Twist [°]:	90
	CCP-40CF <sub>3</sub>	6.00 %	V <sub>10</sub> [V]:	1.23
10	PGU-2-F	5.00 %		
	CGUQU-2-F	10.00 %		
	CGUQU-3-F	10.00 %		
	CCH-35	5.00 %		
	CC-3-V1	10.00 %		

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